Diyala University
College of Agriculture
Animal Resources Department

Principles of Genetics

Dr. Khalid Hamid Hassan

Section no. (1)

Define the following terms

- **gene** is a specific sequence of nucleotide bases, whose sequences carry the information required for constructing proteins, which provide the structural components of cells and tissues as well as enzymes for essential biochemical reactions. The human genome is estimated to comprise more than 30,000 genes

.

- DNA is a stable polynucleotide. The double-helix structure of the DNA molecule in terms of: the components of DNA nucleotides; the sugar-phosphate backbone; specific base pairing and hydrogen bonding between polynucleotide strands (only simple diagrams of DNA structure are needed; structural formulae are not required). Explain how the .structure of DNA is related to its functions

Mutations •

New forms of alleles arise from changes • (mutations) in existing alleles

Mitosis •

Mitosis increases cell number in growth and • tissue repair and in asexual reproduction. During mitosis DNA replicates in the parent cell, which divides to produce two new cells, each containing an exact copy of the DNA of the parent cell. Candidates should be able to name and explain the stages of mitosis and recognise each stage from diagrams and photographs.

. •

Meiosis •

During meiosis, cells containing pairs of • homologous chromosomes divide to produce gametes containing one chromosome from each homologous pair. In meiosis the number of chromosomes is reduced from the diploid number (2n) to the haploid number (n). (Details of meiosis (.not required

Gene Therapy and Cystic Fibrosis

- In gene therapy healthy genes may be cloned and used to replace defective genes. In cystic fibrosis the transmembrane regulator protein, CFTR, is defective. A mutant of the gene that produces CFTR results in CFTR with one missing amino acid. The symptoms of cystic fibrosis related to the malfunctioning .of CFTR

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Principles of Genetics

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Section no. (1)

Principles OF Genetics

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The history of Genetics :

- The history began with general observations, Zebras always produce Zebras never blue birds and Cotton always produce seeds for Cotton never Oranges or any thing else .
- Every one who observes , reasons that parents must pass hereditary informations to their offspring .

- Genetics began its development as independent science with initiation of Mendel's experiments on heredity in 1865 , he reported his discoveries of the fundamental laws of inheritance , but this observations and interpretations were not recognized as such for35 years , part of the reason for this delay was the absence of an understanding of cell structure and cell division
- Mendel's paper was discovered in 1900 by *devries* , *correns* and *Tschermak* independently ., so the year 1900 is important for the beginning of the modern genetics because scientists described the cell structure and cell division .

- During the last half of the 20th century genetics have determined the molecular structure of Mendel's Factors and the mechanism by which they control the characters of an organism .
- Genetics has many relationships and impacts with other sciences :
- In Medicine, defective genes place human at a risk for developing many diseases, and the treatment of inherited disorders by gene therapy hope that has great potential in the future .
- In Agriculture , one of the greatest achievements was the application of Mendel's principles to the development of hybrid corn ,hence during the period from 1940 to 1980 the average yield for corn increased by over 250 percent .

- Selective breeding programs have produced chickens that are meatier , grow faster and more disease resistance and lay more eggs .
- Selective breeding programs have also produced cattle and sheep that are meatier, grow faster and have better adaptation to regional environments , and the milk production per cow also increased.
- The new genetic technologies have a major impact on Agriculture , inserting genes for resistance to insects or pathogens in to crop plants is becoming a major weapon in the war against organisms that destroy plants .

There are three main branches of modern genetics

:

1- Molecular Genetics (or Molecular Biology), which is the study of heredity at the molecular level, and so is mainly concerned with the molecule DNA. It also includes genetic engineering and cloning, and is very trendy. This unit is mostly about molecular genetics.

2- Classical or Mendelian Genetics, which is the study of heredity at the whole organisms level by looking at how characteristics are inherited. This method was pioneered by Gregor Mendel (1822-1884). It is less fashionable today than molecular genetics, but still has a lot to tell us.

3- Population Genetics, which is the study of genetic differences within and between species, including how species evolve by natural selection.

Darwin's theory

- Darwin's theory of evolution by natural selection stated that organisms with traits that are beneficial produce larger numbers of progeny than organisms with less beneficial traits .
- As a result , these beneficial traits become the norm in the population .
- Francis Galton , suggested that the genetic of the human species could be improved through the use of artificial selection , an idea he called *Eugenics* :

Eugenics :

- Parents expressing favorable traits would be encouraged to have larger families , and parents with undesirable traits would be encouraged not to have children . This traits include high intelligence , high levels of achievement and excellent health .

Genotype and phenotype

- He word genotype refersto the alleles an individual receieves at fertilization , genotype may be indicated by letters (DD; Dd) or by short descriptive phrases (homozygous dominant , …..) .
- The word Phenotype refers to the physical appearance of the individual ,thus the homozygous dominant individual and the heterozygous individual both show the dominant phenotype and are tall (DD and Dd) , while the homozygous recessive individual show the recessive phenotype and is short (dd) .

Genotype Versus Phenotype

Genotype	Genotype	Phenotype
DD	Homozygous dominance	Tall plant
Dd	Heterozygous	Tall plant
dd	Homozygous recessive	Short plant

Practice Problems

- Q 1; In rabbits , if W : dominant black allele and w : recessive white allele which of these genotypes could a white rabbit have ? Ww , WW , ww .
- Q 2; In horses ,trotter (P) is dominant over pacer (p) .A trotter is mated to a pacer , and the offspring is a pacer . Give the genotype of all horses ?

- Q 3; In humans, freckles is dominant over no freckles . A man with freckles reproduces with a woman with freckles , but the children have no freckles . What chance did each child have for freckles ?
- Q 4; In Pea plants , yellow seed color is dominant over green seed color .give the genotype of all plants that could possibly produce green peas , when crossed with a heterozygote ? (G= yellow g= green)

Homozygous and Heterozygous

- When an organism has two identical alleles , we say it is Homozygous and this organism produce one kind of gamete (DD Homozygous produce only D kind gamete) and (dd Homozygous recessive produce only d kind gamete) .
- When an organism has two different alleles at a gene locus , we say it is Heterozygous ,this organism produce two kind of gametes (Dd Heterozygous produce D and d gametes) and when only one allele in a Heterozygous individual Dd is expressed , we say that this allele D is dominant , while the allele d that is not expressed in a Heterozygote is a recessive

Practice Problem

- Q ; For each of the following genotypes , give all genetically different gametes , noting the proportion of each for the individual ? 1- WW 2- Ww 3- Dd 4- DD

Mendel's study of heredity

- Gregor Johann Mendel (1822 -1884) was an Austrian monk , who taught natural science at a local technical high school .
- Previously, he went to the university of Vienna to study science and mathematics .
- When Mendel began his work , most plant and animal breeders believed in the blending theory of inheritance ,it suggest that both sexes contribute equally to a new individual ,they felt that parents of contrasting appearance always produce offspring of intermediate appearance.

Mendel's Experiments

- One reason for Mendel's success is that he chose a suitable experimental material , the garden pea , *Pisum sativum .*
- Mendel obtained many different true-breeding varieties of peas , each distinguished by a particular trait .such as plant height , seeds color , seeds texture .
- Mendel focused on these singular differences between pea strains allowed him to study the inheritance of a trait one at a time .

Monohybrid Crosses

The principles of Dominance and segregation

- In one experiment , Mendel crossed tall and dwarf pea plants to investigate how height was inherited.
- Mendel carefully removed the anthers from one variety before its pollen had matured and then applied pollen from the other variety to the stigma, (a sticky organ on top of the pistil that leads to the ovary).
- The seeds that resulted from these cross-fertilizations were sown the next year , yielding hybrids that were uniformly tall .
- Mendel noted that the dwarf trait seemed to have disappeared in the progeny of the cross, for all the hybrid plants were tall .

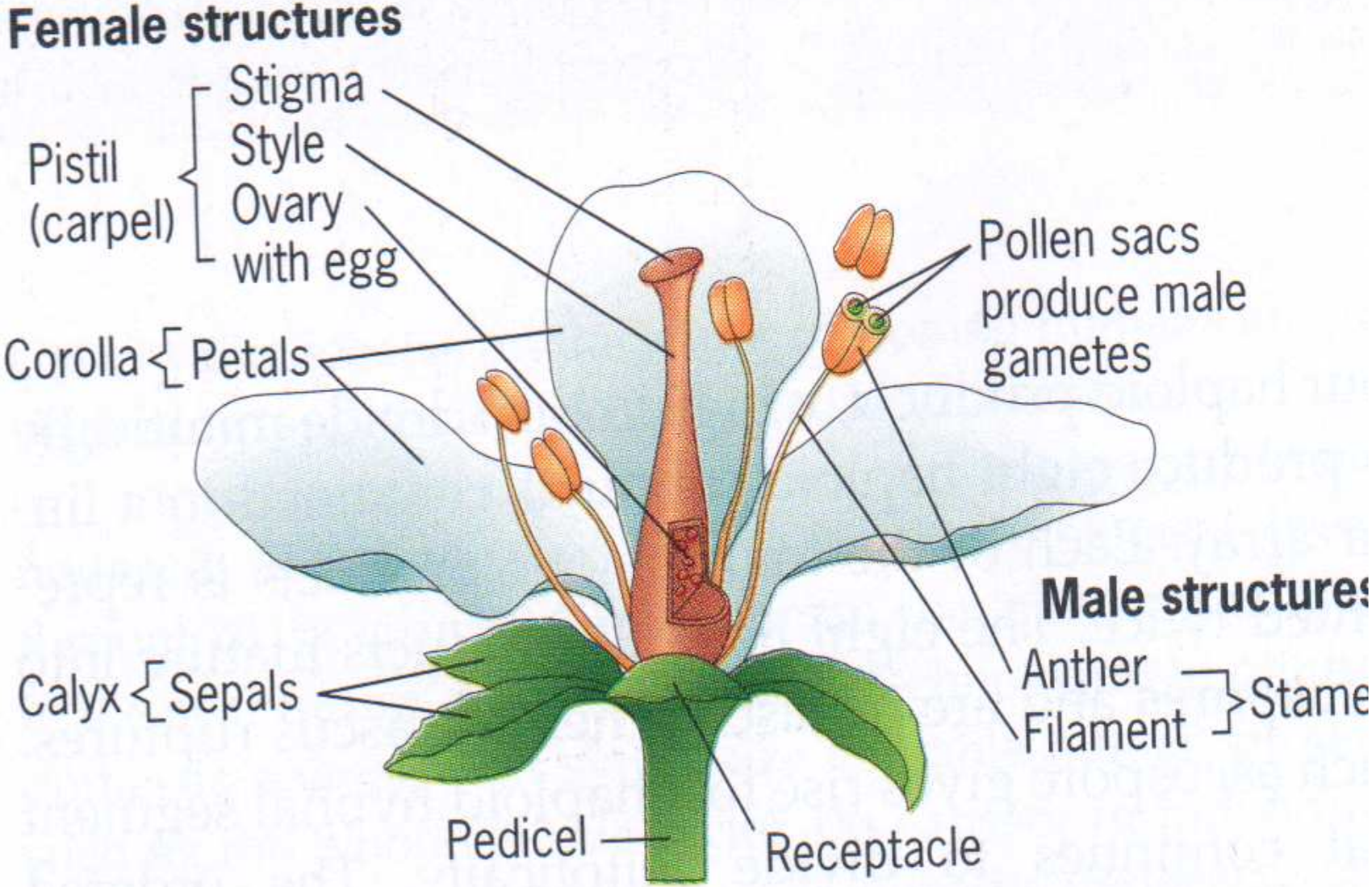
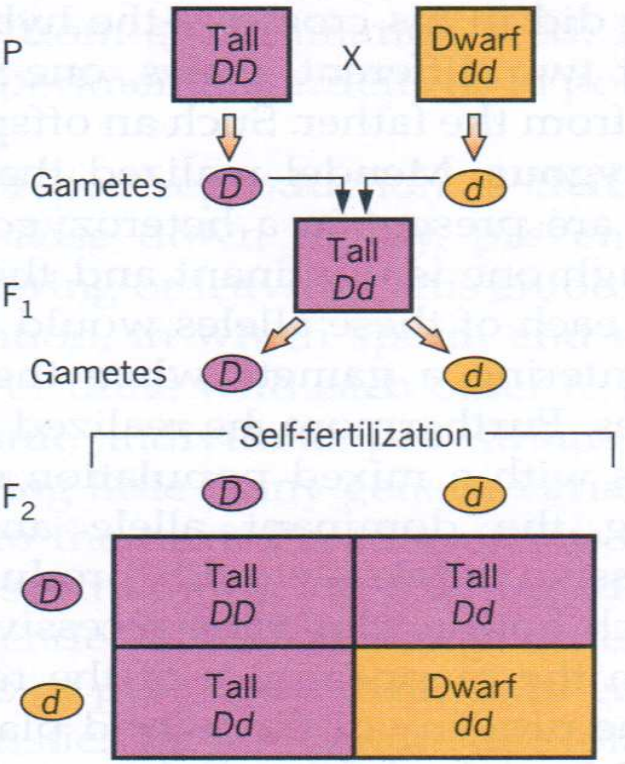


Figure 2.19 The structures of a typical flower, showing

- To explore the hereditary makeup of these tall hybrids Mendel allowed them to undergo self – fertilization, when he examined the progeny , he found that they consisted of both tall and dwarf plants , with ratio of 3 : 1 .
- Clearly , the hybrids that resulted by crossing tall and dwarf varieties had the ability to produce dwarf progeny even though they themselves were tall . Mendel inferred that these hybrids carried a latent genetic factor for dwarfness, one that was masked by the expression of another factor for tallness, he said that the latent factor was recessive and that the expressed factor was dominant .
- Mendel also inferred that these recessive and dominant factors separated from each other when the hybrid plants reproduced .

1. Each parental homozygote produces one kind of gamete.
2. The F_1 heterozygotes produce two kinds of gametes in equal proportions.
3. Self-fertilization of the F_1 heterozygotes yields tall and dwarf offspring in a 3:1 ratio.



F_2	Phenotypes	Genotypes	Genotypic ratio	Phenotypic ratio
	Tall	*DD*	1	3
		Dd	2	
	Dwarf	*dd*	1	1

Figure 3.2 Symbolic representation of the cross between tall and dwarf peas and a summary of the phenotypic and genotypic results.

- Thus , each trait that Mendel studied seemed to be controlled by a heritable factor that existed in two forms , one dominant , the other recessive . (These factors are now called Genes and their dominant and recessive forms are called Alleles
- The important conclusion of Mendel from this experiment: That genes come in pairs, Mendel proposed that each of the parental strains that he used carried two identical copies of a gene and during the production of Gametes, Mendel proposed that these two copies are reduced to one .
- Mendel recognized that the diploid gene number would be restored when sperm and egg unite to form a Zygote .

- Mendel used symbols to represent the hereditary factors .The two true-breeding varieties, tall and dwarf are Homozygous for different alleles of a gene controlling plant height .
- The allele for dwarfness , being recessive, is symbolized by letter (d) . The allele for tallness , being dominant , is symbolized by letter (D) .
- Thus the tall and dwarf pea strains are symbolized by DD and dd respectively .
- Mendel referred to the Parental strains, the (P) generation of the experiment .Their hybrid progeny are are referred to as the first Filial generation (F_1).so the genotype of the F_1 must be Dd (heterozygous) .

- The phenotype of Dd is the same as that of the DD parental strain because D is dominant over d .
- During formation of gamete , the F1 plants produce two kinds of gametes D and d in equal proportions and they segregate from each other
- This process of allele segregation is the most important discovery that Mendel made .

- After self-fertilization , the two kinds of gametes produced four kinds of Zygotes : DD , Dd , dD , and dd . Because of dominance , three of these genotypes have the same phenotype, so the plants in F2 are either tall or dwarf in ratio of 3 : 1 .
- The F2 plants were self-fertilized to produced an F3 , all the dwarf F2 plants produced only dwarf offspring , demonstrating that they were homozygous for the d allele , but the tall F2 plants produced two categories (one-third of them produced only tall offspring whereas the other two-third produced a mixture of tall and dwarf offspring .

We can summarize Mendel's analysis of the Monohybrid crosses by stating two principles that he discovered :

- 1- The principle of dominance ,((In heterozygote , one allele may conceal the presence of another))
- 2- The principle of segregation , ((In a heterozygote , two different alleles segregate from each other during the formation of gametes)) .
- This principle is about genetic transmission , an allele is transmitted to the next generation even if it was present with a different allele in a heterozygote .

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Section no. (2)

Dihybrid Crosses

The Principle of independent Assortment

Dihybrid Crosses

- Mendel performed experiments with plants that differed in two traits , he crossed plants that produced Yellow , Round seeds with plants that produced Green , Wrinkled seeds .
- The F1 seeds were all yellow and round , the alleles for the two seed traits were dominant .
- Mendel grew plants from these seeds and allowed them to self-fertilize ,and classified the F2 seeds according to their phenotype , as following : Two Classes , yellow round and green wrinkled resembled the parental strains. The other two Classes , green round and yellow wrinkled showed new combinations of traits .

- Mendel noticed that the four classes appeared in ratio of (9) yellow round (3) green round (3) yellow wrinkled (1) green wrinkled
- These numerical relationships suggested a simple explanation : each trait was controlled by a different genes segregating two alleles, and the two genes were inherited independently .

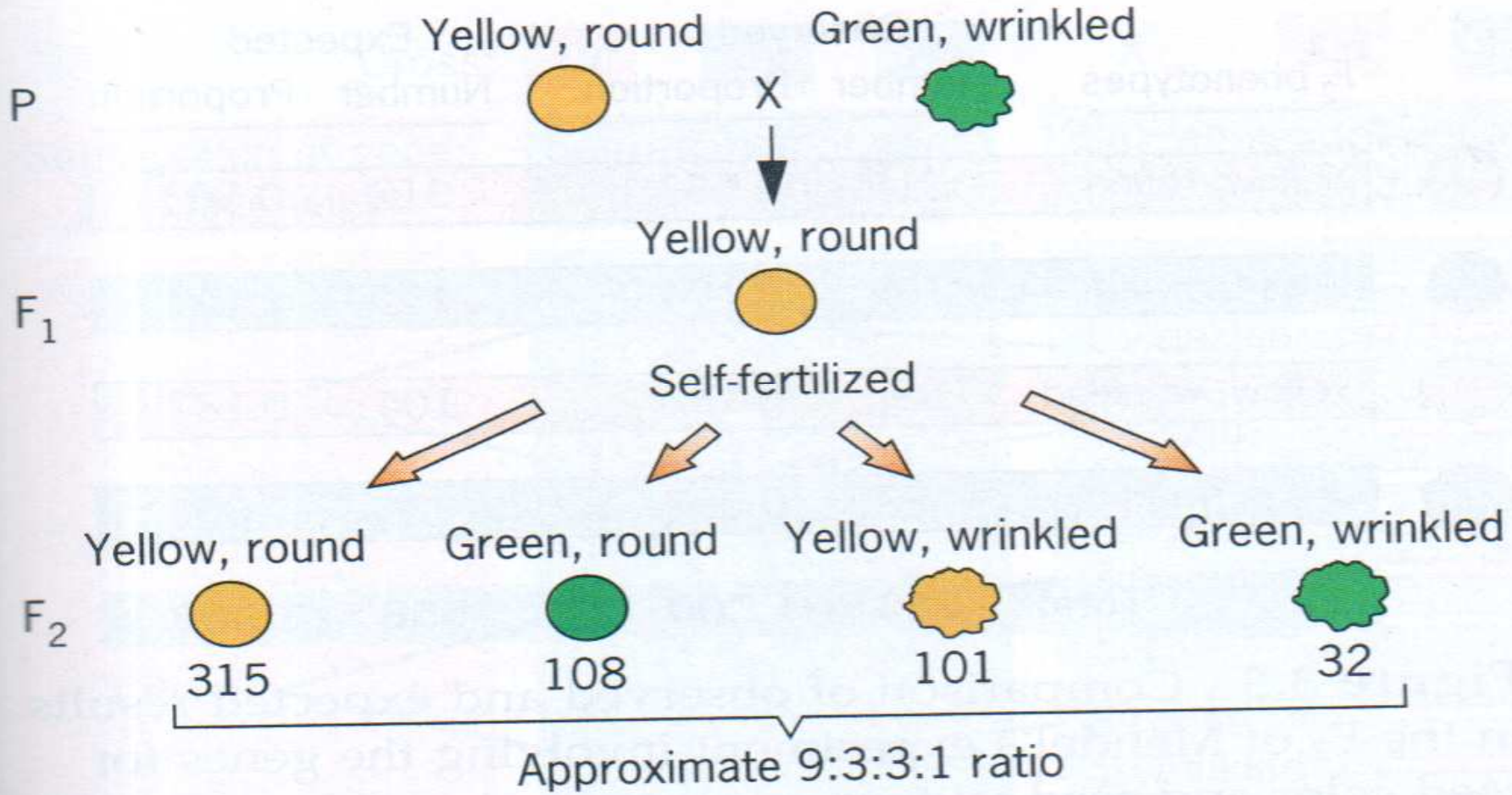


Figure 3.3 Mendel's crosses between peas that produced yellow, round seeds and peas that produced green, wrinkled seeds.

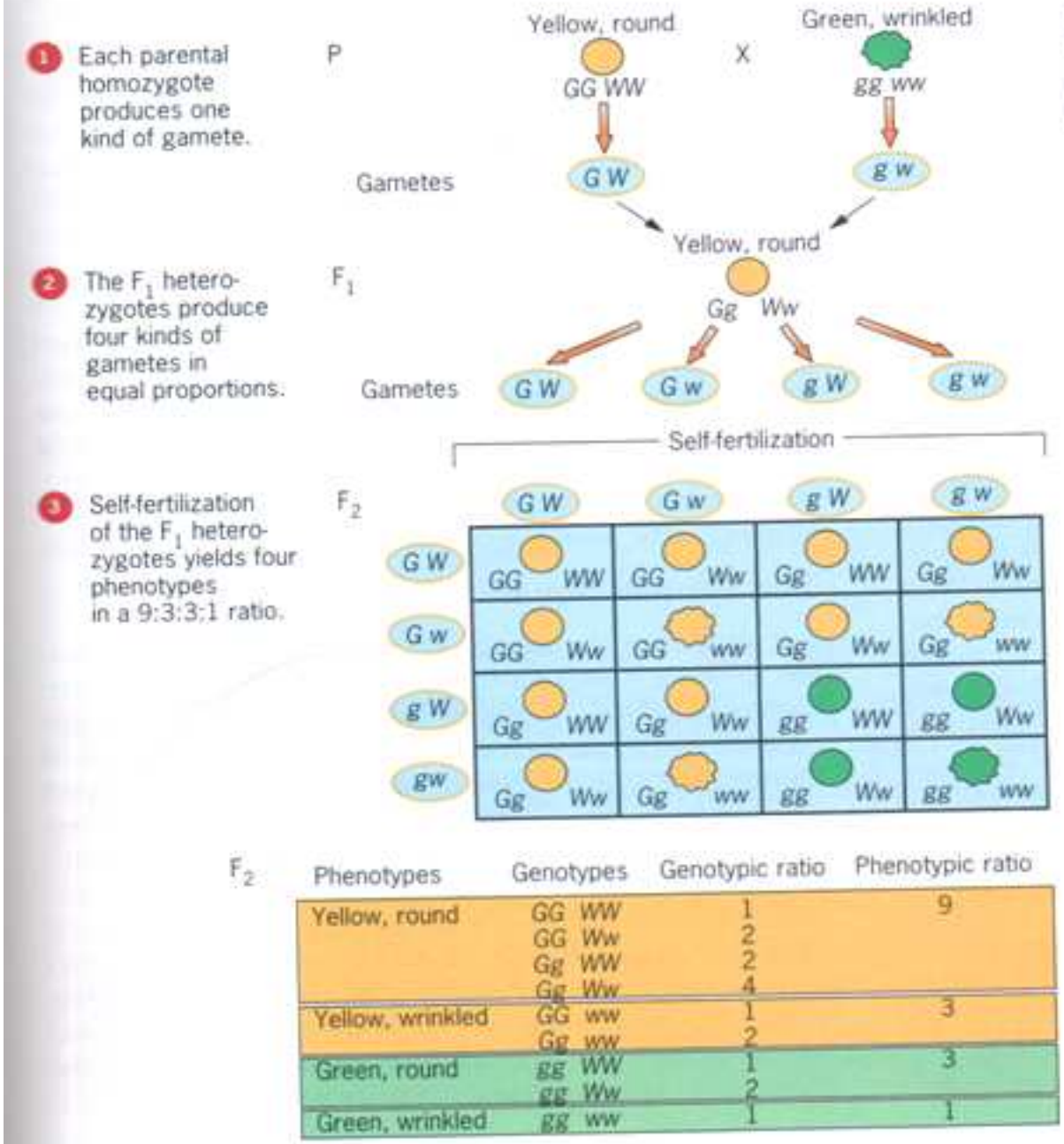


Figure 3.4 Symbolic representation of the results of a cross between a variety of peas with yellow, round seeds and a variety with green, wrinkled seeds.

F_2

Phenotypes	Genotypes	Genotypic ratio	Phenotypic ratio
Yellow, round	GG WW	1	9
	GG Ww	2	
	Gg WW	2	
	Gg Ww	4	
Yellow, wrinkled	GG ww	1	3
	Gg ww	2	
Green, round	gg WW	1	3
	gg Ww	2	
Green, wrinkled	gg ww	1	1

- Let us analyze the results of this two factors using Mendel's methods We denote each gene with a letter , for the seed color gene , the two alleles are g (for green) and G (for yellow) and for seed texture gene , they are w (for wrinkled) and W (for round) .
- The parental strains must have doubly homozygous , the yellow round plants were GGWW and the green wrinkled plants were ggww .
- The haploid gametes produced by a diploid plants contain one copy of each gene , gamete from GGWW plants therefore would be GW . And by similar reason , the gametes from ggww plants are written gw .
- Cross fertilization of these two types of gametes produces F1 hybrids that are doubly heterozygous GgWw and their yellow round phenotype indicates that the G and W alleles are dominant .

- The principle of segregation predicts that the F hybrids will produce four different gametic genotypes : GW , Gw , gW , gw
- If each gene segregates its alleles independently each of the four types will be 25 percent of the total .
- Self-fertilization in the F1 will produce an array of 16 equally frequent zygotic genotypes, while the proportion of the four phenotypic classes were :
  9/16 yellow round , 3/16 yellow wrinkled
  3/16 green round , 1/16 green wrinkled .
- The result of these experiments led Mendel to the principle of independent assortment : ((The alleles of different genes segregate independently of each of each other))

Mendel's experiments established Three basic genetic principles :

- 1- Some alleles are dominant , others recessive .
- 2-During gamete formation , different alleles segregate from each other .
- 3- Different genes assort independently .

Practice Problems

- **Q1**; For each of the following genotypes, give all possible gametes , noting the proportion of each for the individual ? 1- dd GG 2- Dd Gg 3- DD Gg 4- Dd GG

.

- **Q2**;In horses , B= black coat dominant over b = brown coat and P= trotter dominant over p= pacer . A black pacer mated to a brown trotter produce a black trotter offspring, give all possible genotypes for this offspring ?
- **Q3**; In humans , short fingers and widows peak are dominant over long fingers and continous hairline. A heterozygote reproduces with a heterozygote .what is the chance of any one childs having the same phenotype as the parents ?

Practice Problems

Q ; Choose the correct answer from the following ?

1- In humans , pointed eyebrows are dominant over smooth eyebrows . Marys father has pointed eyebrows , but she and her mother have smooth , what is the genotype of the father ?
1- BB 2- Bb 3- bb 4- Any one of these .

2- In guinea pigs , smooth coat R is dominant over rough coat r and black coat W is dominant over white coat w . In the cross Rr Ww x Rr Ww , how many of the offspring will have a smooth black coat ? 1- 9 only 2- 9/16 3- 1/16 4- 6/16 .

Allelic Variation and Gene Function

Degrees of dominance

Genes interaction

Multiple alleles

- Mendel's experiments established that genes can exist in alternate forms , Mendel identified two alleles : one dominance , the other recessive .
- This discovery suggested a simple function between alleles , as if one allele did nothing and the other did every thing to determine the phenotype , The interaction between alleles in the same locus (of the same gene) present the following gene functions of dominant and recessive :
- 1- Complete dominance . An allele is dominant if it has the same phenotypic effect in heterozygote as in homozygote , that the genotype Aa and AA are the same phenotype .

- 2-Incomplete dominance (partial dominance)
  When a heterozygote has a phenotype different from that of either of its associated homozygotes .
- Flower colors in the snapdragon are white and red varieties are homozygous for different alleles of a color gene , when crossed ,they produced heterozygotes that have Pink flowers, the allele for red color (W) is therefore said to be incompletely dominant over the allele for white color (w) .

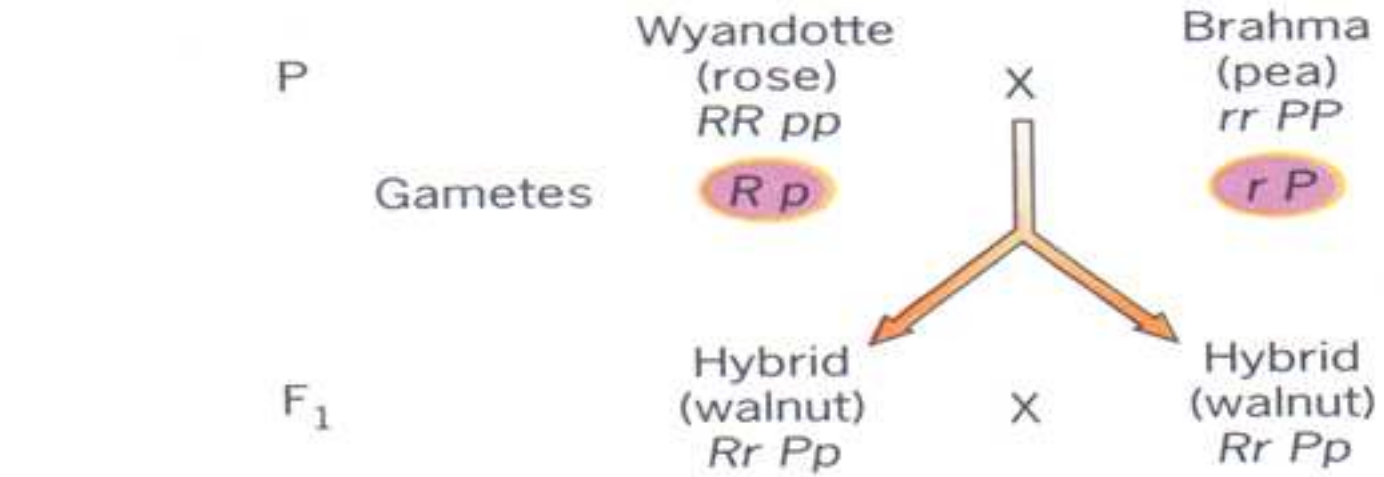
3-Codominant . In this case there is an independence of allele function , neither allele is dominant or even partial dominant over the other .

-

Gene interaction

- Some of the first evidences that a trait can be influenced by more than one gene was obtained by Bateson and Punnett from breeding experiments with chickens .
- Domestic breeds of chickens have :
  Rose comb (Wyandotte chickens)
  Pea comb (Brahmas chickens)
  Single comb (Leghorn chickens)
- Crosses between Wyandottes and Brahmas produce chickens that have another type of comb called Walnut comb .

- Bateson and punnett discovered that comb type is controlled by two independently assorting genes R and P each with two allele ,and the interaction between their product result different phenotype.



Male gametes

F2	R P	R p	r P	r p
R P	RR PP walnut	RR Pp walnut	Rr PP walnut	Rr Pp walnut
R p	RR Pp walnut	RR pp rose	Rr Pp walnut	Rr pp rose
r P	Rr PP walnut	Rr Pp walnut	rr PP pea	rr Pp pea
r p	Rr Pp walnut	Rr pp rose	rr Pp pea	rr pp single

Female gametes

Summary: 9/16 walnut, 3/16 rose, 3/16 pea, 1/16 singl

Figure 4.14 Bateson and Punnett's experiment on comb shape in chickens. The intercross in the F_1 produces four phenotypes, each highlighted by a different color in the

- Wyandottes (with rose combs) have the genotype RRpp and Brahmas (with Pea combs) have the genotype rrPP
- The F1 hybrids between these two varieties are therefore RrPp and the phenotypes are walnut combs .
- If these hybrids are intercrossed with each other, all four types of combs appear in the progeny :

9/16 walnut (R- P-)
3/16 rose (R- pp)
3/16 pea (rr P-)
1/16 single (rr pp)

The Leghorn breed ,which has the single comb type must be homozygous for both of the recessive alleles .

Epistasis

- When two or more genes influence a trait ,an allele of one of them may have an overriding effect on the phenotype, when an allele has such effect it said to be epistatic to the other genes that are involved .And the other gene called hypostatic .
- Example : Most meat type male lines of broiler breeder parents are dominant white because they have an autosomal gene that inhibits the production of color in the feathers .The White Leghorn is the only pure colored birds with inhibitor gene that prevent expression of the genes for colored feathers .

- The inhibitor gene is dominant and symbolized as I and its recessive allele enable genes for colored feathers to produce their effects and symbolized as i .
- If a dominant white male II CC crossed with a colored female ii CC all offspring would be white feathers , as following :

parents (P) II CC × ii CC

gametes I C ↓ i C

F1 Ii CC

- The epistasis cause deviation from mendelians proportion in the F2 progeny of the following cross :
- When White Leghorn II CC crossed with White Silkie ii cc the results would be :
- Parent (P) II CC × ii cc
  gametes I C ↓ i c
  F1 (intercrossed) Ii Cc × Ii Cc
  gametes I C , I c ,I C,I c ↓
  F2 9/16 (I- C-), 3/16 (ii C-) ,3/16(I- cc) ,1/16(ii cc)
  The phenotypic ratio would be : 13 white : 3 colored

Pleiotropy

- Not only is it true that a phenotype can be influenced by many genes , but also true that a gene can influence many phenotypes , it is said Pleiotropic
- For example ; from the study of mutations affecting the formation of bristles in Drosophila, wild type flies have long ,smooth curved bristles on the head and thorax . Flies homozygous for singed bristles mutation have short, twisted bristles on these body parts . This gene also needed for the production of healthy , fertile eggs , we know this fact because females that are homozygous for singed mutation are completely sterile , they lay flimsy ,ill formed eggs that never hatch. However these mutation no adverse effect on male fertility .Thus , the singed gene pleiotropically controls the formation of both bristles and eggs in females and formation of bristles in males .

Multiple Alleles

- Sometimes there are more than two alleles for a given chromosome locus in which case a trait is controlled by multiple alleles . each individual has only two of all the available alleles .
- The classical example for this case is ,In rabbits there are 4 alleles for coat color, and there is a dominance sequence as follow : $c^{+} > c^{ch} > c^{h} > c.$

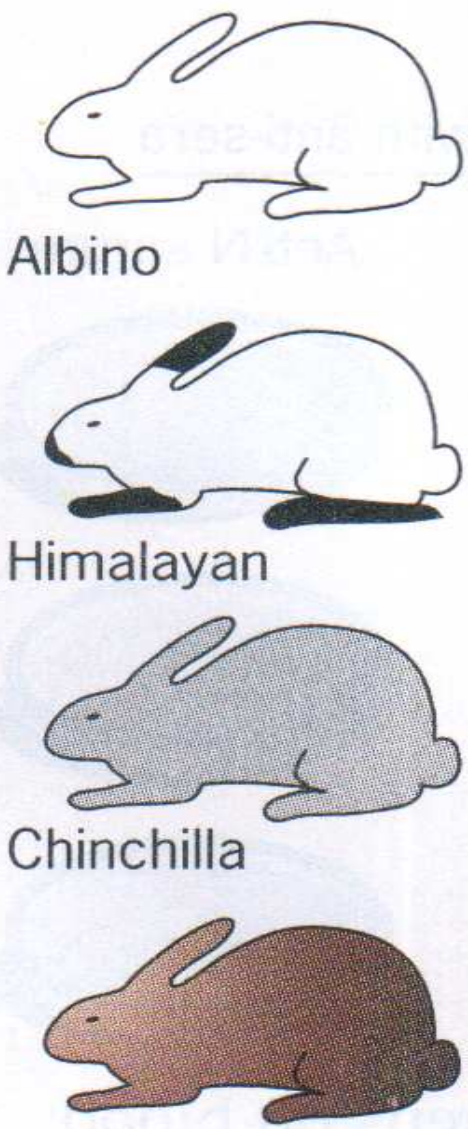


Figure 4.3 Coat colors in rabbits. The different phenotypes are caused by four different alleles of the *c* gene.

Allelic series

- The functional relationships among the membersof series of multiple alleles can be studied by making heterozygous .
- For example; the four alleles of the c gene in rabbits can be combined with each other to make six different kinds of heterozygotes

$$c\,c^{h};\,c\,c^{ch};\,c\,c^{+};\,c^{h}c^{ch};\,c^{h}c^{+};\,c^{ch}c^{+}$$

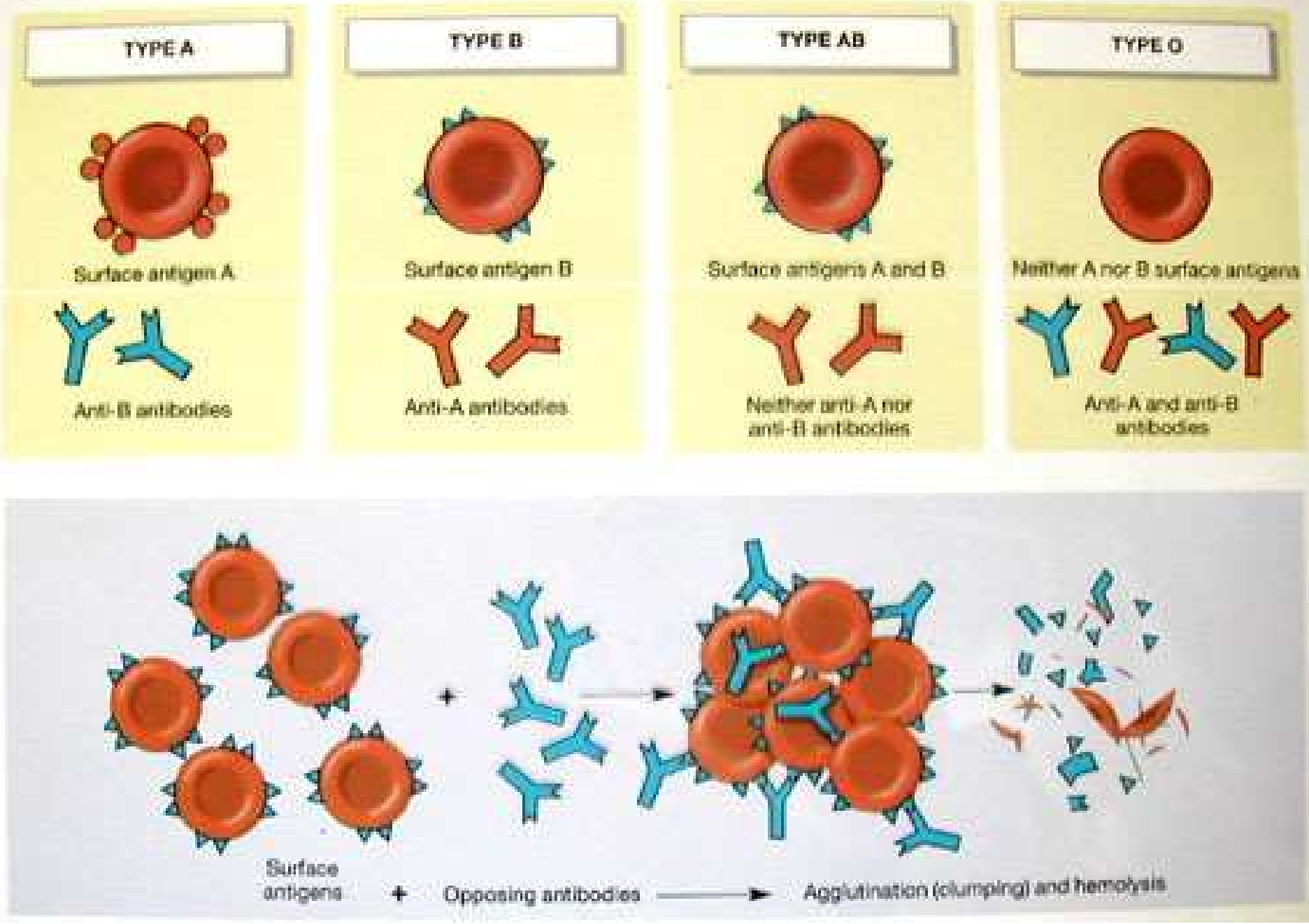
ABO Blood groups iheritance

- Another example of multiple alleles comes from the study of human blood types, the A , B , AB , and O blood types are identified by testing a blood sample with different sera , one serum detects the A antigen another the B antigen .
- When only the A antigen is present on the cells, the blood is type A .
  When only the B antigen is present on the cells, the blood is type B .
- When both antigens are present, the blood is type AB .and when neither antigen is present ,it is type O .

- The blood typing for A and B antigens is completely independent of blood typing for M and N antigen .
- The A allele and B allele are codominant scince each is expressed equally in the heterozygous AB , and O allele is recessive to both the A and B alleles .

Fig. 11-6

Blood Typing and Cross Reactions



Genotypes, Phenotypes, and Frequencies in the ABO Blood-Typing System

Genotype	Blood Type	A Antigen Present	B Antigen Present	Frequency in U.S. White Population (%)
I^AI^A or I^AI^O	A	+	−	41
I^BI^B or I^BI^O	B	−	+	11
I^AI^B	AB	+	+	4
I^OI^O	O	−	−	44

The inheritance of blood groups in human

I^AI^A I^AI^O	A
I^BI^B or I^BI^O	B
I^AI^B	AB
I^OI^O	O

Genotypes of Crosses		progeny	phenotype
I^AI^A x I^AI^A	=	I^AI^A	= A
I^AI^A x I^OI^O	=	I^AI^O	= A
I^BI^B or I^BI^O x I^BI^B	=	I^BI^B or I^BI^O	= B
I^BI^B x I^AI^A	=	I^AI^B	= AB
I^AI^B x I^OI^O	=	I^AI^O or I^BI^O	= A or B

Practice problem

- Q ; A person with type A blood reproduces with a person with type B blood and produce child with type O blood , what the genotype of the parents ?
- Q ; From the following blood types , determine which baby belongs to which parents ?

Parents		Progeny	
Mrs. Doe	Type A	Baby 1	Type O
Mr. Doe	Type A	Baby 2	Type A
Mrs. Jones	Type AB		
Mr. Jones	Type A		

The inheritance of M and N blood Types

- There are two kinds of serum , one serum called anti-M , which recognizes only the M antigen on human blood cells . Another serum , called anti-N , recognizes only the N antigen on the cells. When one of these sera detects its specific antigen in blood – typing test , the cell clump together causing a reaction called agglutination .
- The ability to produce the M and N antigens is determined by a gene with two alleles . One allele allows the M antigen to be produced , the other allows the N antigen to be produced . Homozygotes for the M allele produce only the M antigen .and homozygotes for the N allele produce only the N antigen .

- The heterozygotes for these two alleles produce both kinds of antigens because the two alleles appear to contribute equally to the phenotype of the heterozygotes . So they are said to be Codominant .
- The different genotypes shown in the following :

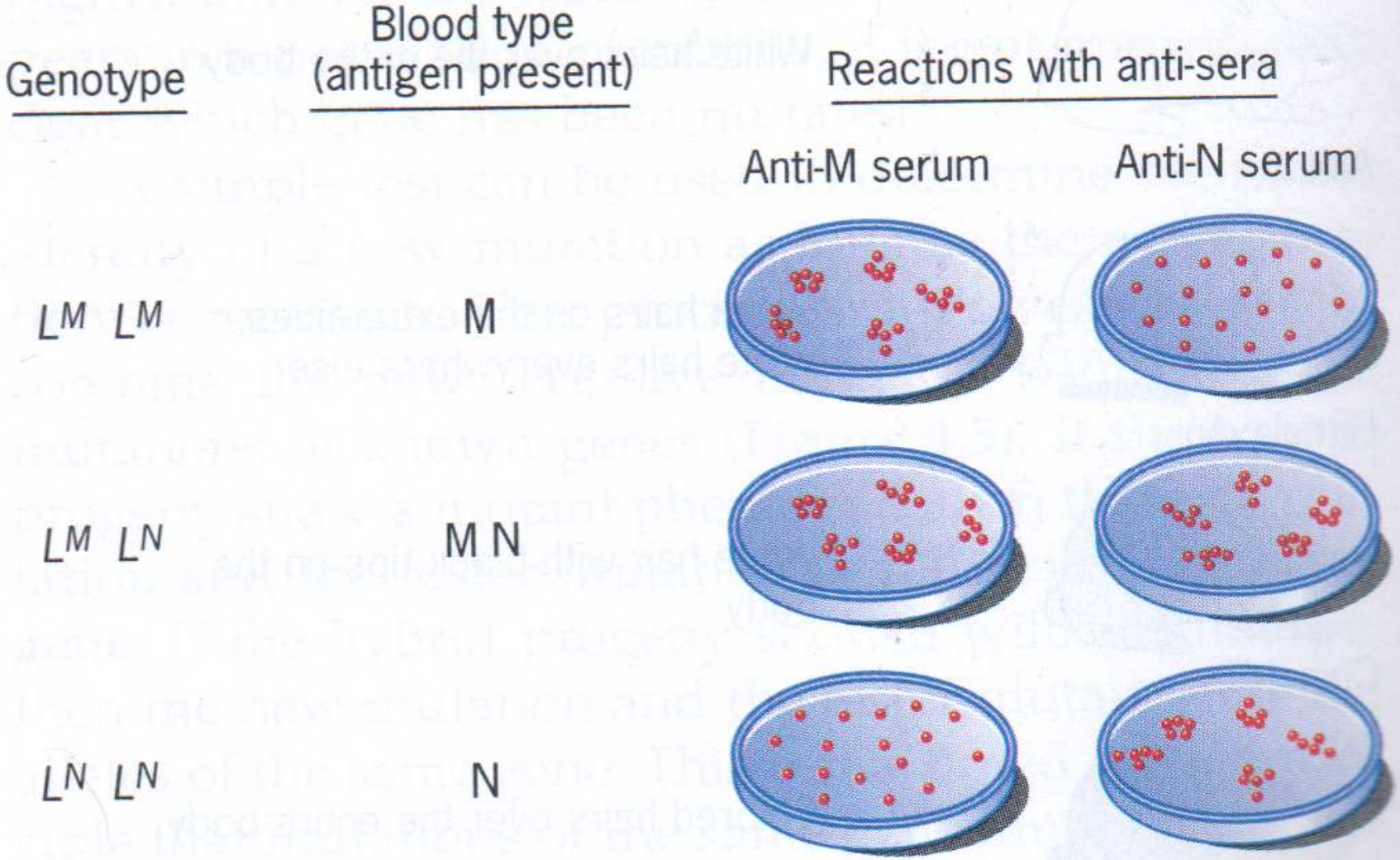


Figure 4.2 Detection of the M and N antigens on blood cells by agglutination with specific anti-sera. With the anti-M and anti-N sera, three blood types can be identified.

The Rh Blood Factor

- Rh Factor ; Antigen in the red blood corpuscles of certain people . A pregnant Rh negative woman carrying an Rh positive child may develop antibodies , causing the child to develop a hemolytic disease .
- The Rh blood factor is inherited separately from types A , B , AB , or O type blood , in each instance, it is possible to be Rh positive or Rh negative.

- When you are Rh positive ,there is a particular antigen on the red blood cells, and when you are Rh negative, it is absent . It can be assumed that the inheritance of this antigen is controlled by a single allele pair in which simple dominance prevails.
- The Rh positive allele is dominant over the Rh negative allele , complications a rise when an Rh negative woman reproduces with an Rh positive man and the child in the womb isRh positive , the woman may begin to produce antibodies that will attack the red blood cells of this baby or of a future Rh positive baby .

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Principles of Genetics

Dr. Khalid Hamid Hassan

Section no. (4)

Sex Inheritance

- Sex chromosome : chromosomes were discovered in the second half of the nineteenth century by a German cytologist W. Woldeyer , the chromosomes are best seen by applying dyes to dividing cell .
- One pair of the chromosomes called sex-chromosome which responsible of sex determination and sexual traits , the other pairs of chromosomes called autosomal chromosomes .
- In some animal species – for example, grasshopers females have one more chromosome than males , this extra chromosome originally observed in other insects , is called X chromosome or we called sex - chromosome.

Sex Determination

1- Males heterogametic system •

A-The XX – XO system •

B-The XX – XY system •

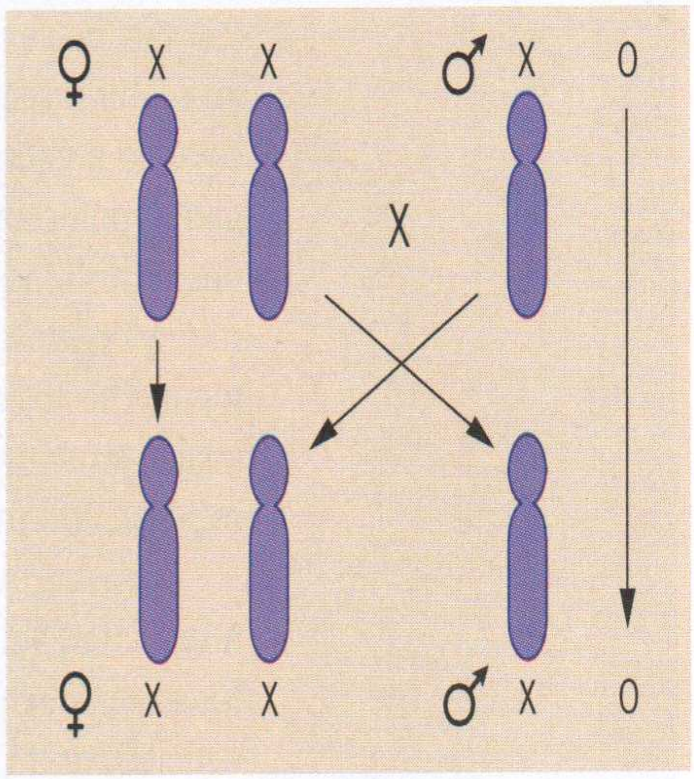
2- Males homogametic system •

A- The ZZ – ZW system •

B- The ZZ – ZO system. •

3- Haploid – Diploid system. •

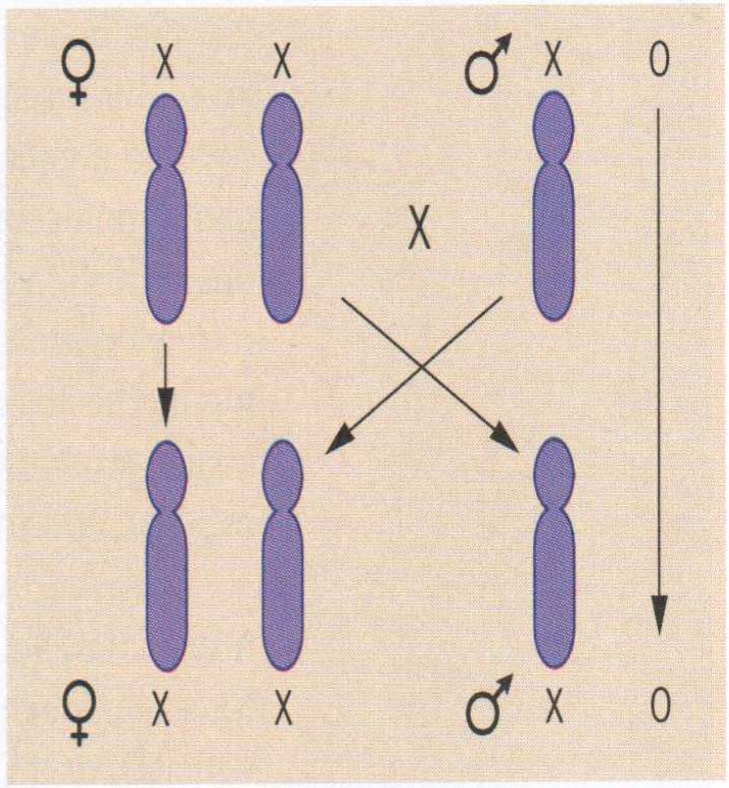
A- The XX – XO system



(a) Inheritance of sex chromosomes in animals with XX females and XO males.

- A- The XX – XO system .
- Females of these species have two X chromosomes and males have only one , thus females are cytologicaly XX and males are XO where the O denotes the absence of a chromosome .
- During meiosis in the female, the two X chromosomes pair and then separate ,producing eggs that contain a single X chromosome.

A- The XX – XO system

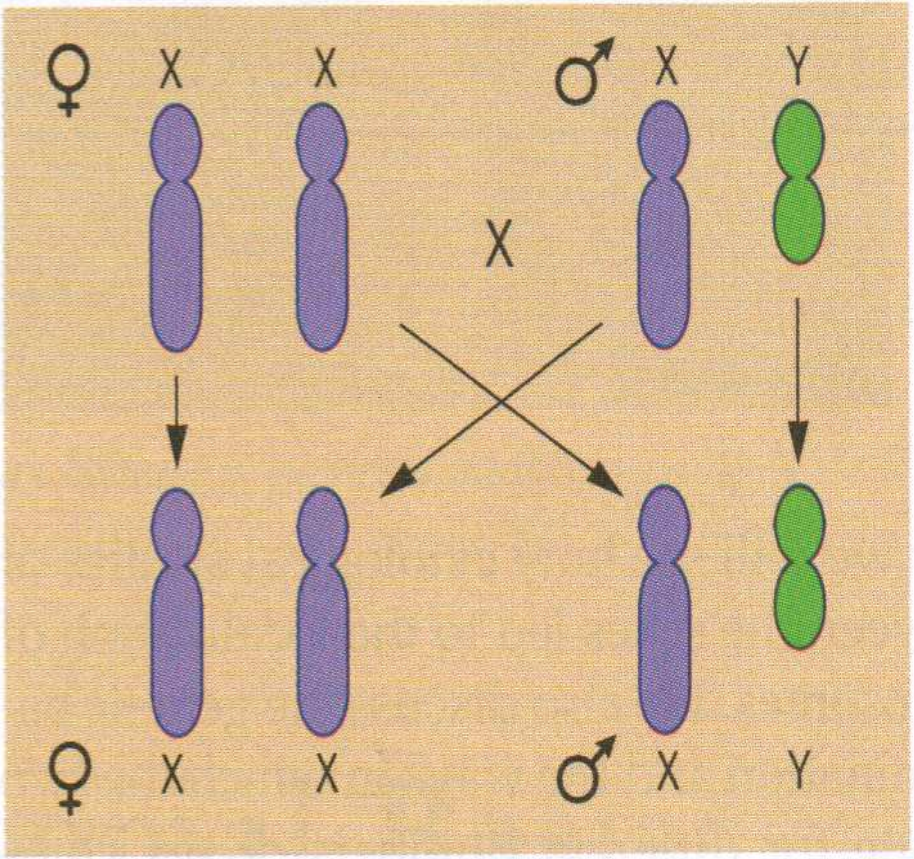


(a) Inheritance of sex chromosomes in animals with XX females and XO males.

- During meiosis in the male , the solitary X chromosome moves independently of all the other chromosomes and appear in half the sperms, the other half receive no X chromosome.
- Thus , when sperms and eggs unite ,two kinds of zygotes are produced . XX which develop into females and XO which develop into males , and the reproduction mechanism produce

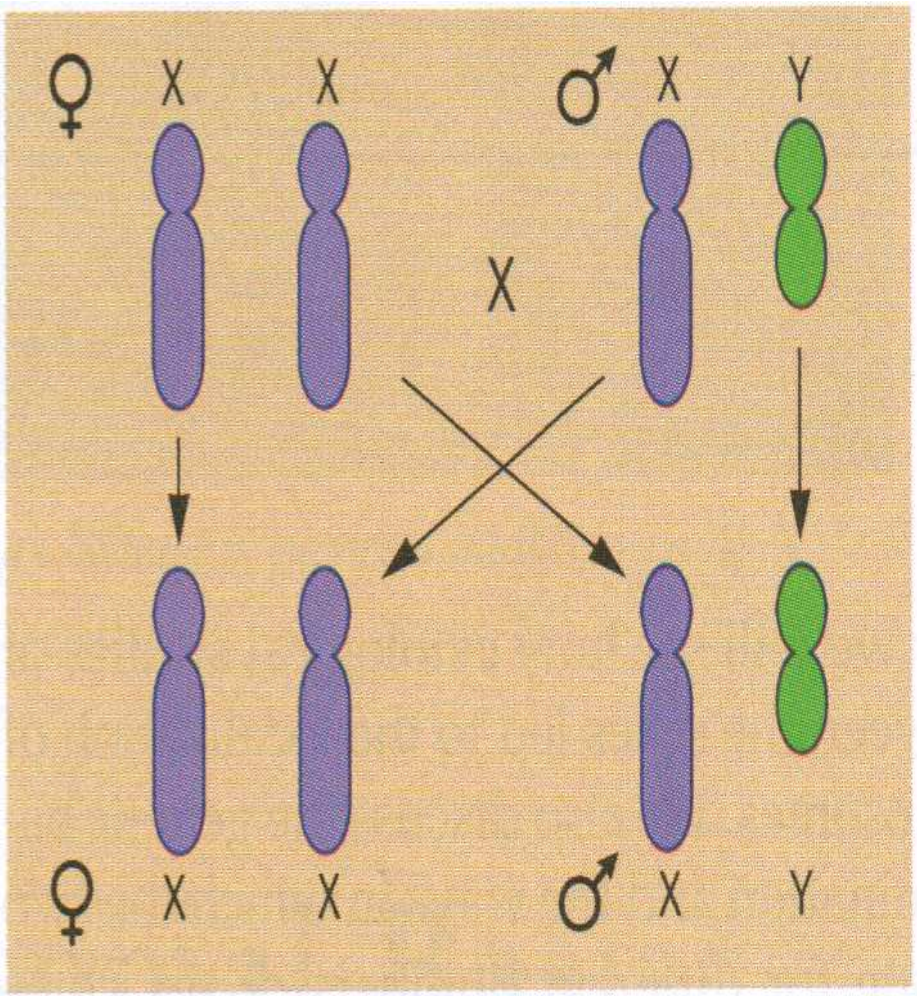
a 1 : 1 ratio of males to females in these species .

B- The XX – XY system



(b) Inheritance of sex chromosomes in animals with XX females and XY males.

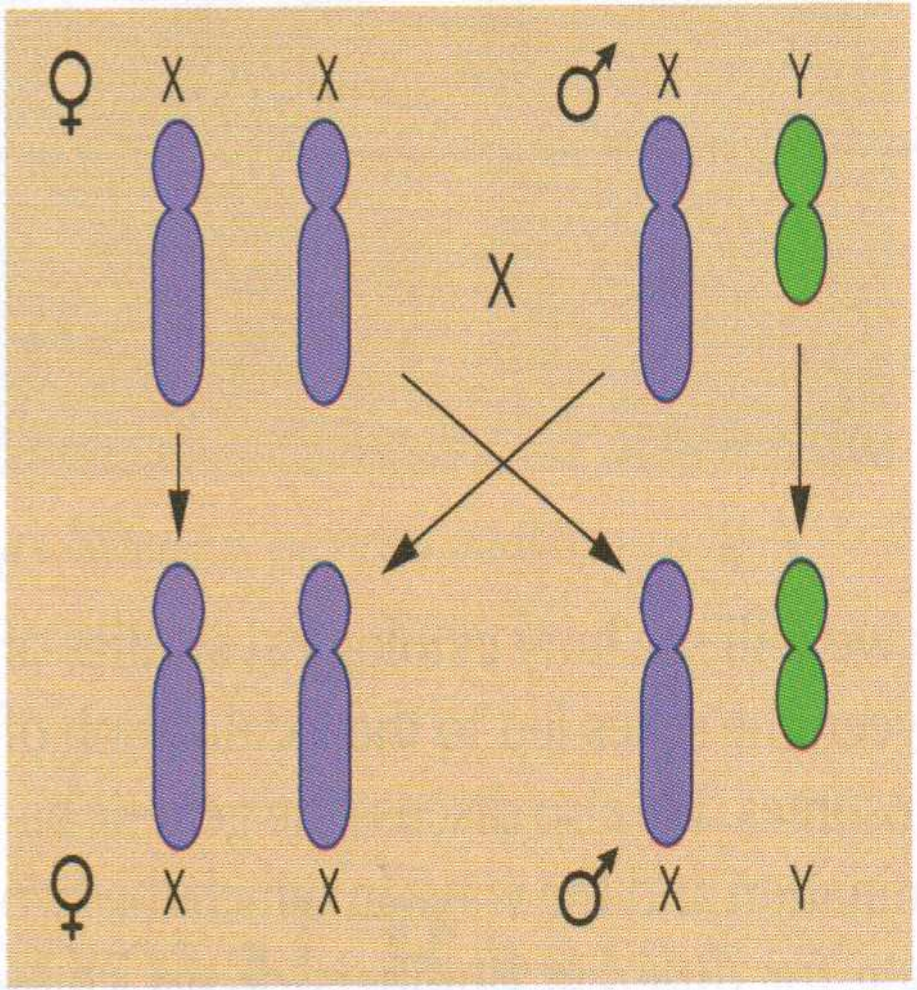
- In many other animals , including human beings ,and Drosophila males and females have the same number of chromosomes , this numerical equality is due to the presence of a chromosome in the male , called the Y chromosome which pairs with the X chromosome during meiosis ..



(b) Inheritance of sex chromosomes in animals with XX females and XY males.

- The Y chromosome morphologically different from the X chromosome , In human (for example) the Y is much shorter than X and its centromer is located closer to one of the ends .
- During the meiosis in the male , the X and Y chromosomes separate from each other , producing two kinds of sperms , X-bearing and Y-bearing , while XX females produce only one kind of eggs which is X-bearing .
- If fertilization were to occur randomly approximately half the zygotes would be XX and the other half would be XY leading to a 1 : 1 sex ratio .

Sex Determination in human beings



(b) Inheritance of sex chromosomes in animals with XX females and XY males.

- The discovery that human females are XX and that human males are XY suggested that sex might be determined by the number of X chromosomes or by the presence or absence of a Y chromosome . As we know , the second hypothesis is correct,

- In human and other placental mammals , maleness is due to a dominant effect of the Y chromosome , The evidence for this fact comes from the study of individuals with an abnormal number of sex chromosomes .
- The XO animals develop as females, and XXY animals develop as males .
- The dominant of the Y chromosome is manifested early in the development, when it directs the primordial gonads to develop in to test, once the testes have formed they secrete testosterone , a hormone that stimulates the development of male secondary sex characters .

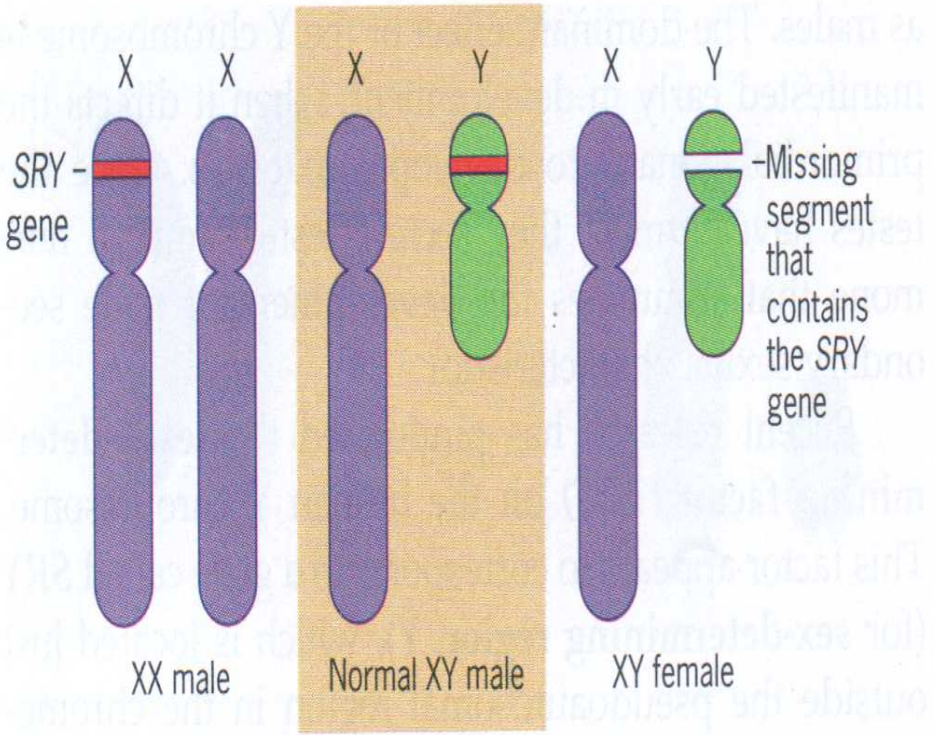
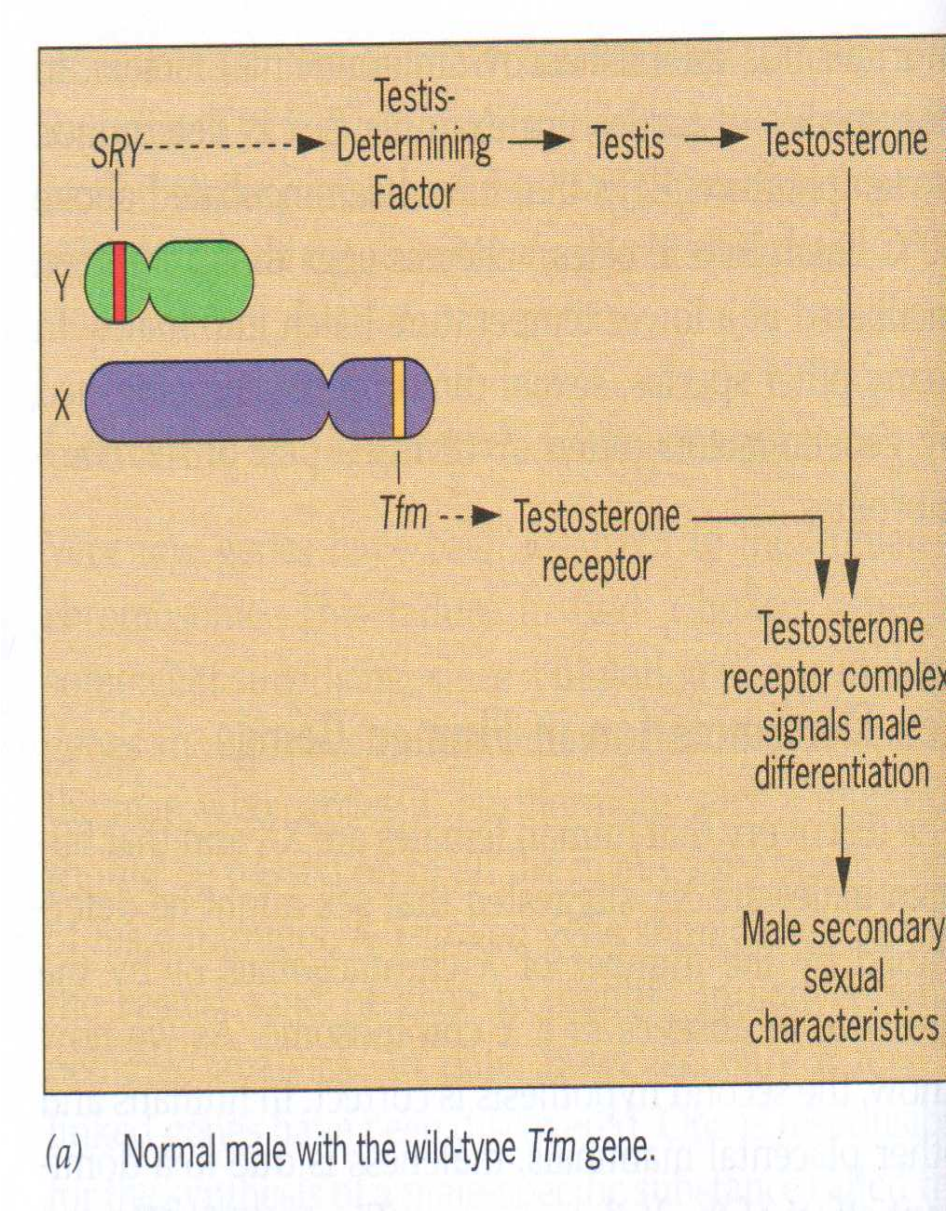


Figure 6.13 Evidence localizing the gene for the testis-determining factor (TDF) to the short arm of the Y chromosome in normal males. The TDF is the product of the *SRY* gene. In XX males, a small region containing this gene has been inserted into one of the X chromosomes, and in XY females, it has been deleted from the Y chromosome.

- Recent research has pointed that there is a factor produce from a gene called (SRY) sex determining region Y



(a) Normal male with the wild-type *Tfm* gene.

- .The discovery of SRY in unusual individuals whose sex was in consistent with their chromosome constitution XX males and XY females .

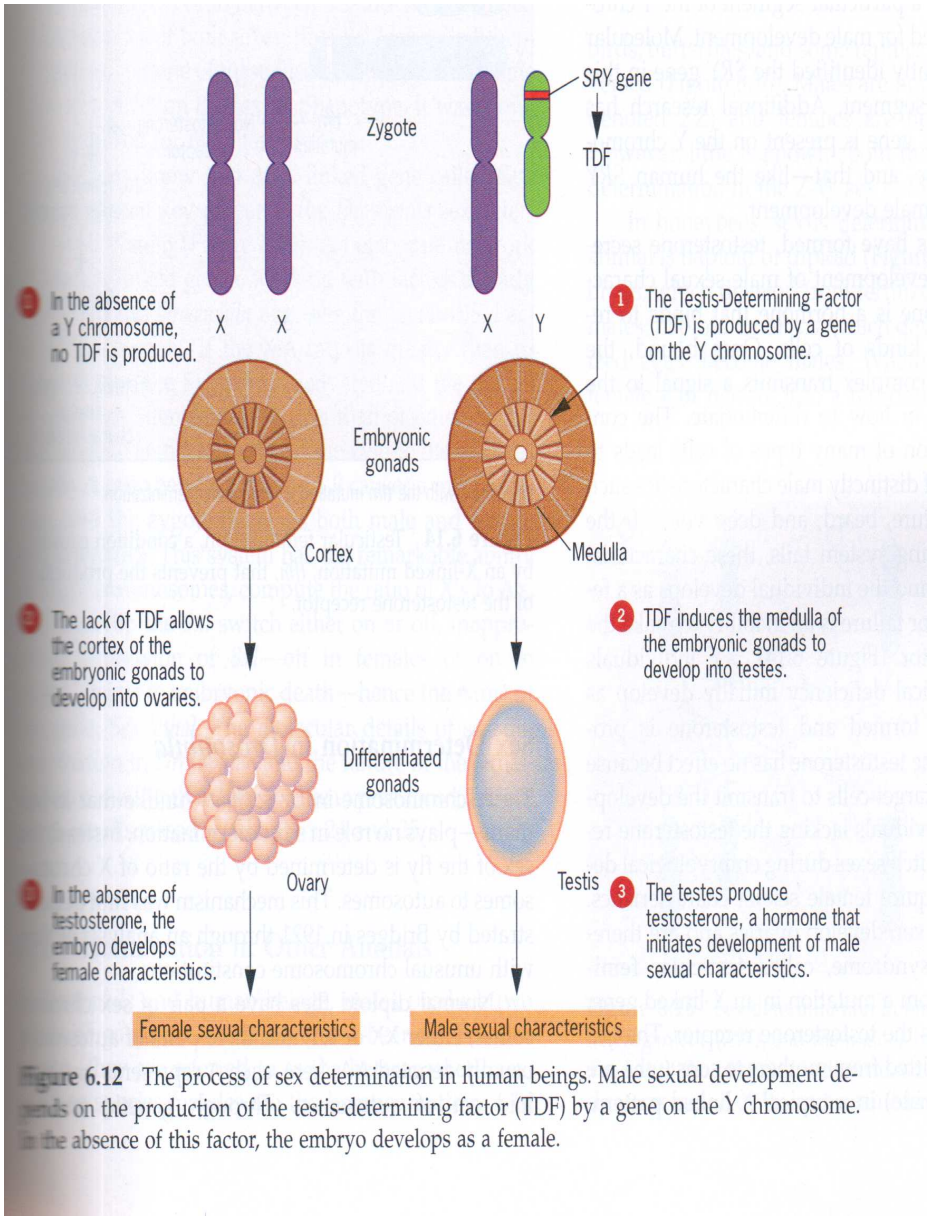
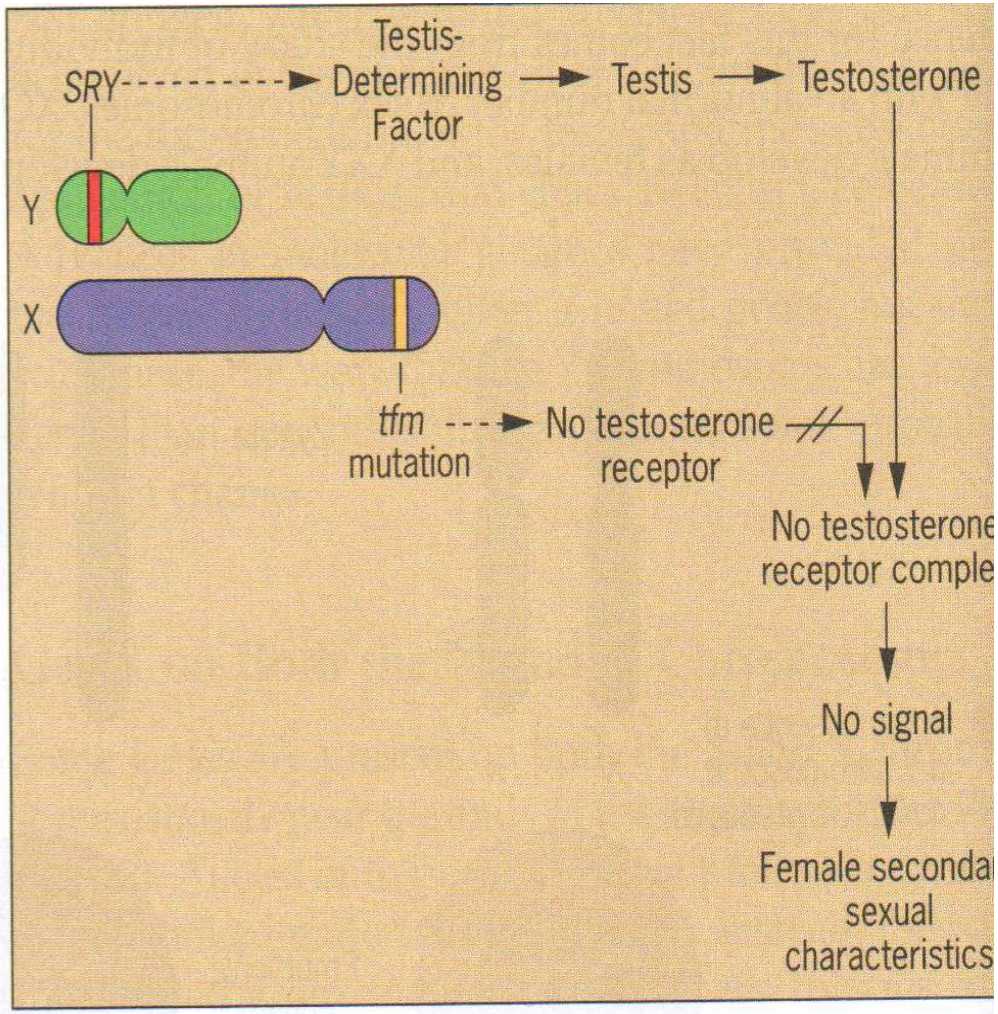


Figure 6.12 The process of sex determination in human beings. Male sexual development depends on the production of the testis-determining factor (TDF) by a gene on the Y chromosome. In the absence of this factor, the embryo develops as a female.

- Some of the XX males were found to carry a small piece of the Y chromosome inserted into one of the X chromosomes , this piece evidently carried a gene responsible for maleness .



(b) Male with the *tfm* mutation and testicular feminization.

Figure 6.14 Testicular feminization, a condition caused by an X-linked mutation, *tfm*, that prevents the productio of the testosterone receptor.

- Some of the XY females were found to carry an incomplete Y chromosome that was missing the piece that was present in the XX male .

2- Males homogametic system

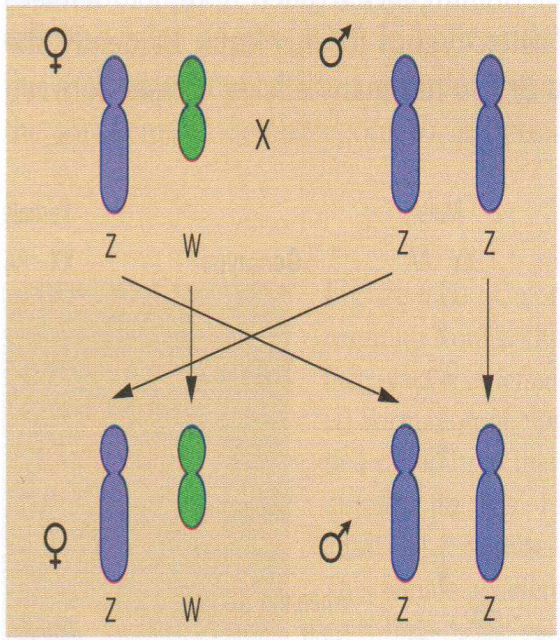


Figure 6.16 Sex determination in birds. The female is heterogametic (ZW), and the male is homogametic (ZZ). The sex of the offspring is determined by which of the sex chromosomes, Z or W, is transmitted by the female.

- A- The ZZ – ZW system

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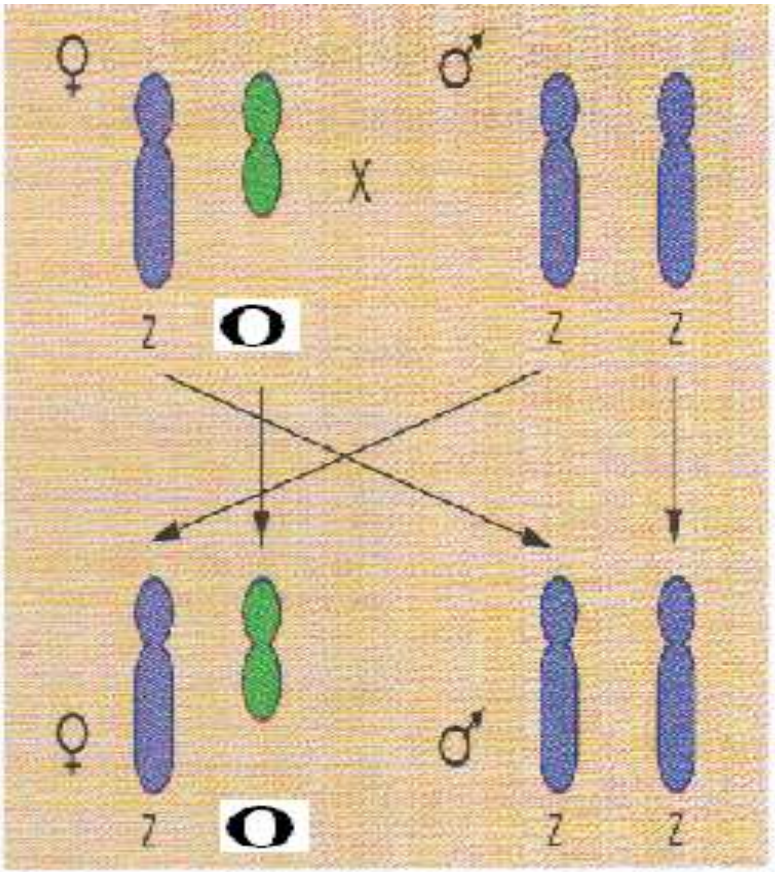
- In bird , butterflies and some reptile , this situation is revered , Males are homogametic (usually denoted ZZ) and females are heterogametic (ZW) .



B- The ZZ – ZO system.

- In chickens there is no evidence about the presence of W chromosome , so we denoted to the females ZO and the males ZZ .

3- Haploid – Diploid system.

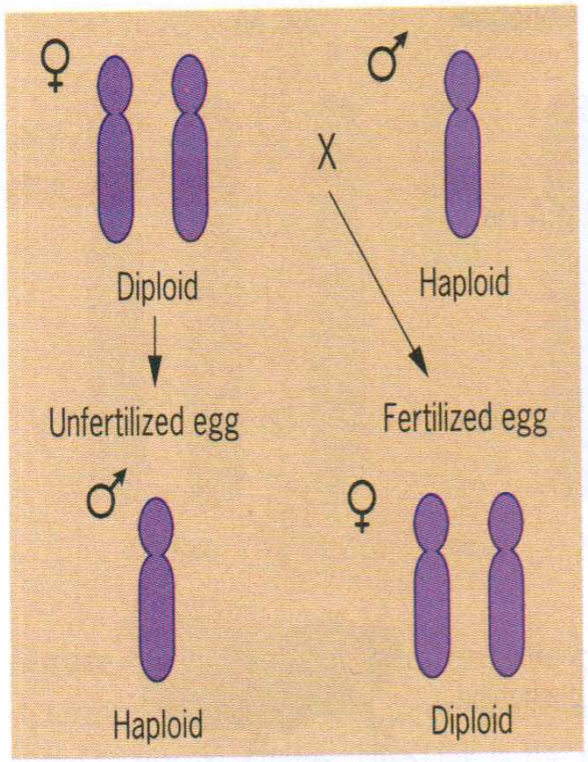


Figure 6.17 Sex determination in honeybees. Females, which are derived from fertilized eggs, are diploid, and males, which are derived from unfertilized eggs, are haploid.

- In honey bees, sex is determined by whether the animal is haploid or diploid .
- Diploid embryos, which develop from fertilized eggs ,become females , haploid embryos , which develop from unfertilized eggs, become males .
-

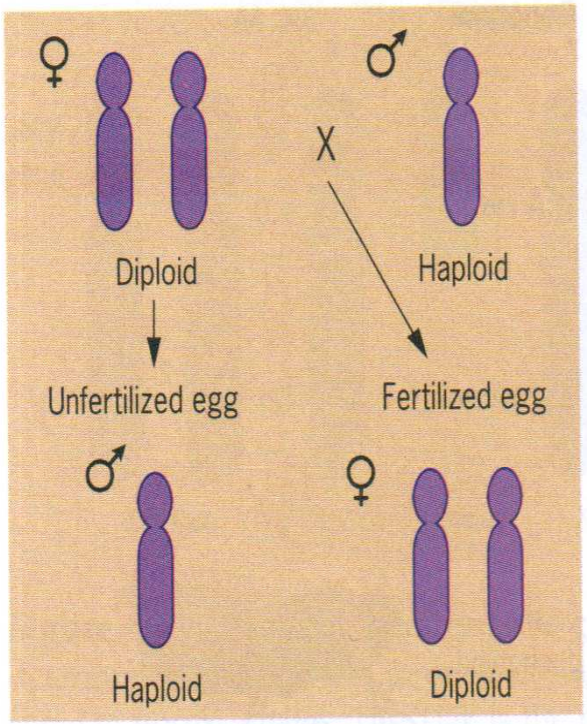


Figure 6.17 Sex determination in honeybees. Females, which are derived from fertilized eggs, are diploid, and males, which are derived from unfertilized eggs, are haploid.

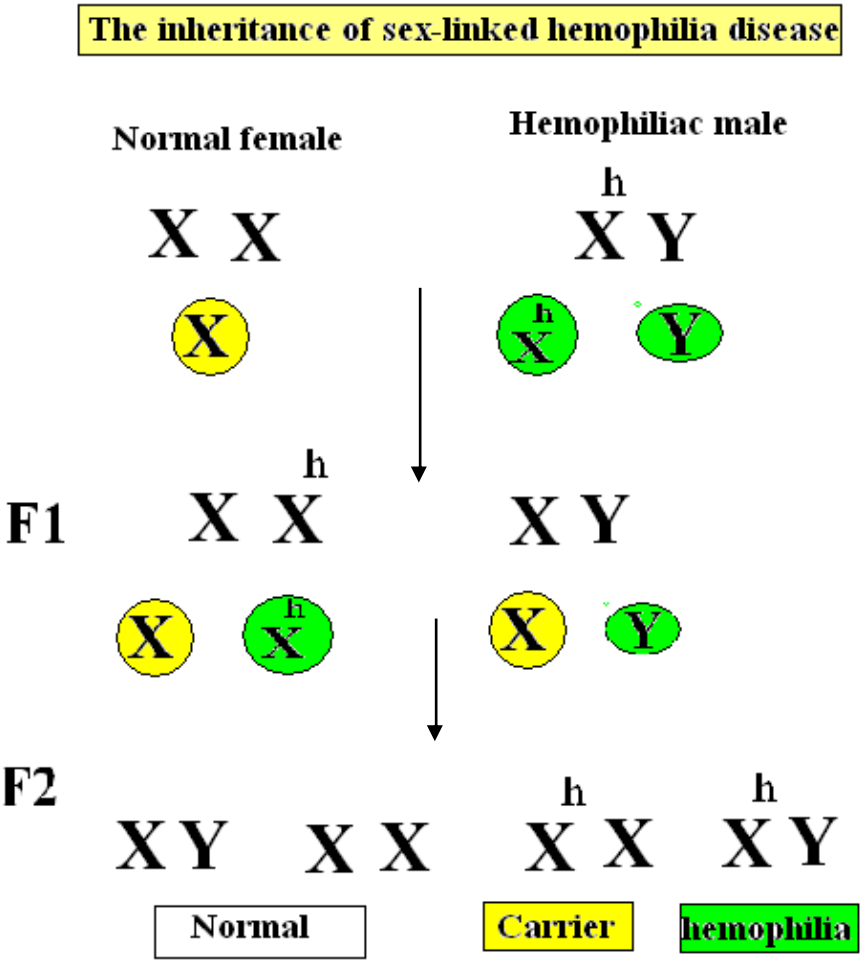
- Whether or not a given female will mature into a reproductive form (queen) depends on how she was nourished as a larva . In this system , a queen can control the ratio of male to females by regulating the proportion of unfertilized eggs that she lays .

Sex –Linked Genes

- Genes which located on X chromosome called sex –linked genes , and the traits influenced with these genes called sex-linked traits .
- In human beings , recessive x-linked traits are much more easy identified than are recessive autosomal traits , a male needs only to inherit one recessive allele to show an x-linked trait . However, a female needs to inherit two recessive allele (one from each of her parents) to show an x-linked trait . Thus , the most appearance of x-linked traits are in the males ..

- The x-linked trait disappear in the first generation and reappear in the second generation .
- Another example for x-linked trait is the color blindness in human beings , a heterozygous female carrier has a chance for transmitting the mutant allele to her children .

Hemophilia , an X-linked disease



- In human beings , a certain type of hemophilia is one of the best known example of an x-linked trait , people with this disease are unable to produce a factor needed for blood clotting(the cut and wounds of hemophiliacs continue to bleed and can cause death)
- Nearly all the individuals affected with x-linked hemophilia are males .

The inheritance of white eye sex-linked mutant in drosophila

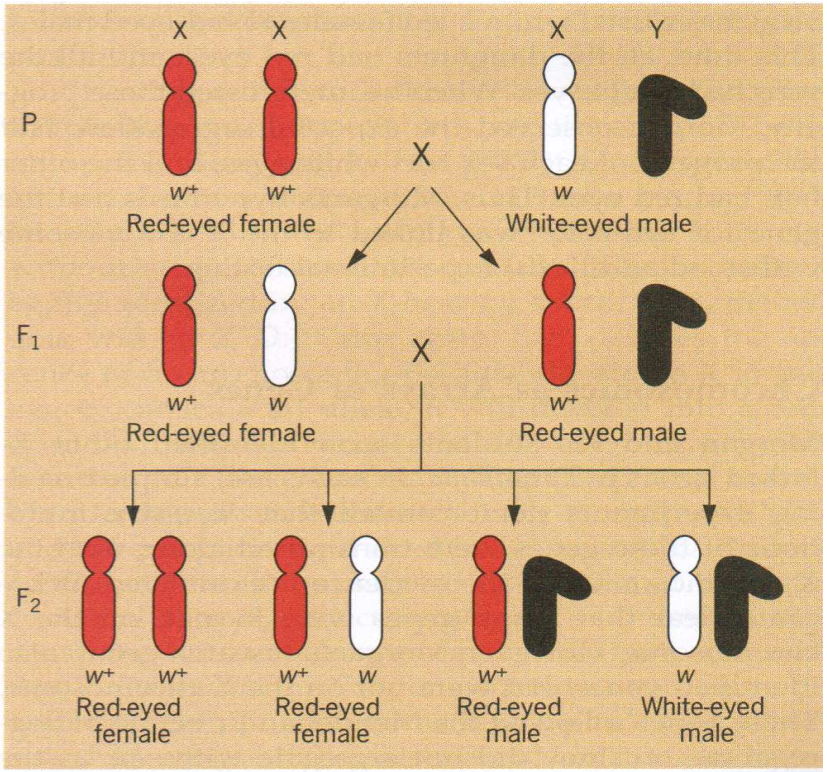
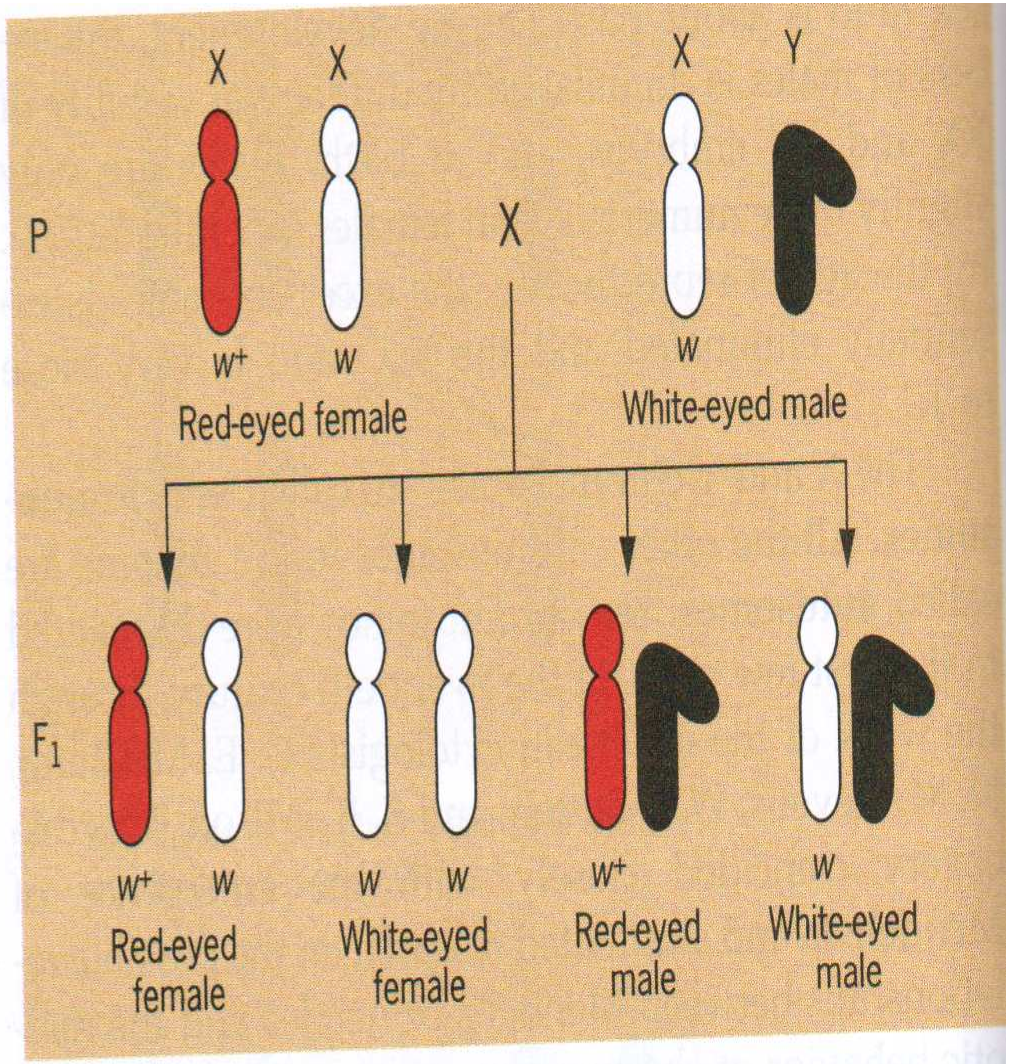


Figure 6.3 Morgan's experiment studying the inheritance of white eyes in *Drosophila*. The transmission of the mutant condition in association with sex suggested that the gene for eye color was present on the X chromosome but not on the Y chromosome.

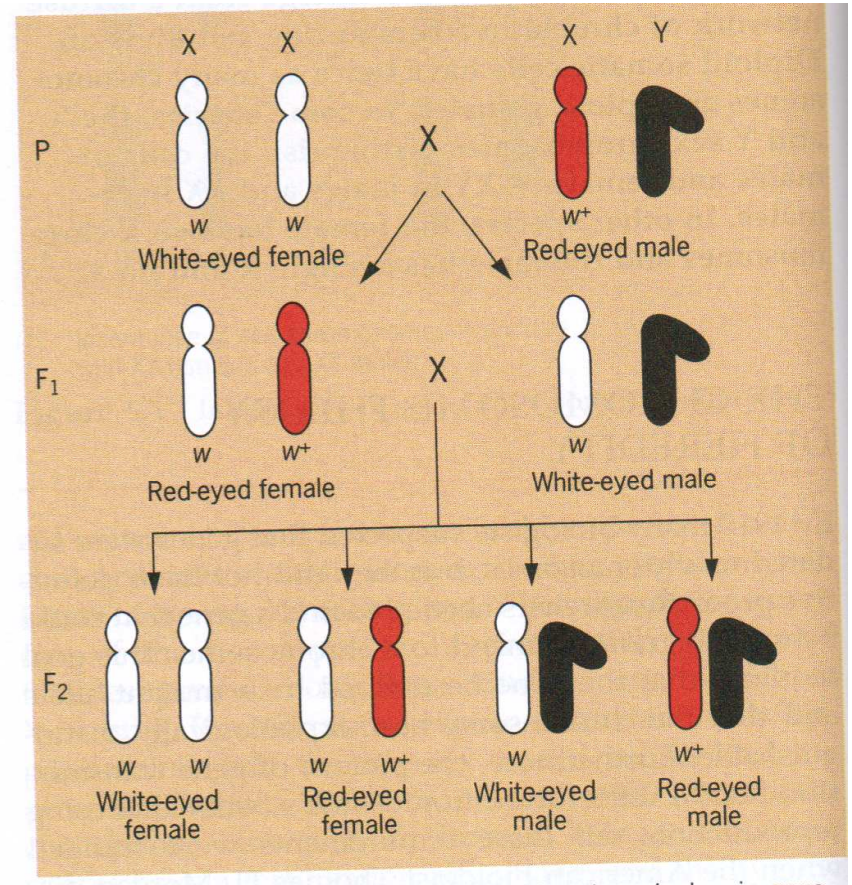
- The development of chromosome theory depended on the discovery of the white eye mutation in Drosophila , this mutation was a recessive allele of an x-linked gene .



(a) Cross between a heterozygous female and a hemizygous mutant male.

- In male one allele can show the phenotype of the trait , while in the female needs two homozygous recessive alleles to appear the trait .

The crisscross inheritance



(b) Cross between a homozygous mutant female and a hemizygous wild-type male.

- With the x-linked trait appear the crisscross inheritance , in this case the female pass her x-linked trait to sons and the male pass his x-linked trait to daughter .The homogamete sex must carry the homozygote recessive x-linked gene to express the phenotype of the trait . As following :

Sex influenced trait

- Some genes not located on the X chromosome or Y chromosome are expressed differently in the two sexes, and therefore they referred to as sex-influenced traits .
- An example for this traits is the index finger length , an index finger equal to or longer than the fourth finger is dominant in females but recessive in males .

Practice problems

- Q1; If a father and son both have color blindness, is it likely that the son inherited the trait from his father ?
- Q2: Both the mother and father of a hemophilic son appear to be normal . From whom did the son inherit the gene for hemophilia ? What is the genotype of the mother, the father, and the son ?
- Q3:Aman is sex linked color blind . If he reproduces with a woman who is homozygous normal, what is the chance that sons will be color blind ? Daughters will be color blind ? Will be carrier ?
- Q4; A normal woman, whose father had hemophilia, marries a normal man . What is the chance that their first child will have hemophilia ?

Diyala University
College of Agriculture
Animal Production Department

Principles of Genetics

Dr. Khalid Hamid Hassan

Section no. (3)

DNA: The Genetic Material

- Even though Morgan was able to confirm that the genes are on the chromosomes , the scientists still did not know what genes consisted of , they knew that the genetic material must be :
- 1-able to store information that is used to control both the development and metabolic activities of the cell or organism .
- 2-stable so that it can be replicated with high fidelity during cell division and be transmitted from generation to generation .
- 3-able to undergo rare changes called Mutations to generate genetic variability that is acted upon during evolution .

The Discovery of DNA

- DNA was first identified in 1869 by Friedrich Miescher, a Swiss biologist, removed the nuclei of pus cells (these cell have little cytoplasm) and found that they contained a chemical material , he called nuclein, which , he said , rich in phosphorous and had no sulfur, that properties distinguished it from protein , and separated the substance into a basic part (which we now know is DNA) and an acidic part (a class of acidic proteins that bind to basic DNA).
- Later the scientists realized that there are two types of nucleic acids : DNA (deoxyribonucleic acid) and RNA (ribonucleic acid)

Transformation of Bacteria :

- In 1928 , the bacteriologist Frederick Griffith performed an experiment with a bacterium (*streptococcus pneumoniae*) that causes pneumonia in mammals .
- He noticed that when these bacteria are grown on culture plate , some , called S strain bacteria , produce shiny , smooth colonies and others called R strain bacteria , produce colonies that have a rough appearance under the microscope , S strain bacteria have a mucous coat but R strain don't .

- When Griffith injected mice with the S strain bacteria they died , and when he injected mice with the R strain bacteria , they did not die .
- In an effort to determine if the smooth coat was responsible for the virulence (ability to kill) of the S strain , he injected mice with heat –killed S strain bacteria , the mice did not die .
- Finally , Griffith injected mice with a mixture of heat-killed S strain and live R strain bacteria , unexpectedly , the mice died and living S strain bacteria were recovered from their bodies .

- He concluded that some substance necessary to produce a mucous
- Coat which cause virulence must have passed from the dead S strain to the living R strain . So that the R strain bacteria were transformed
- Now the question a rise what the transforming substance which cause transformation ?

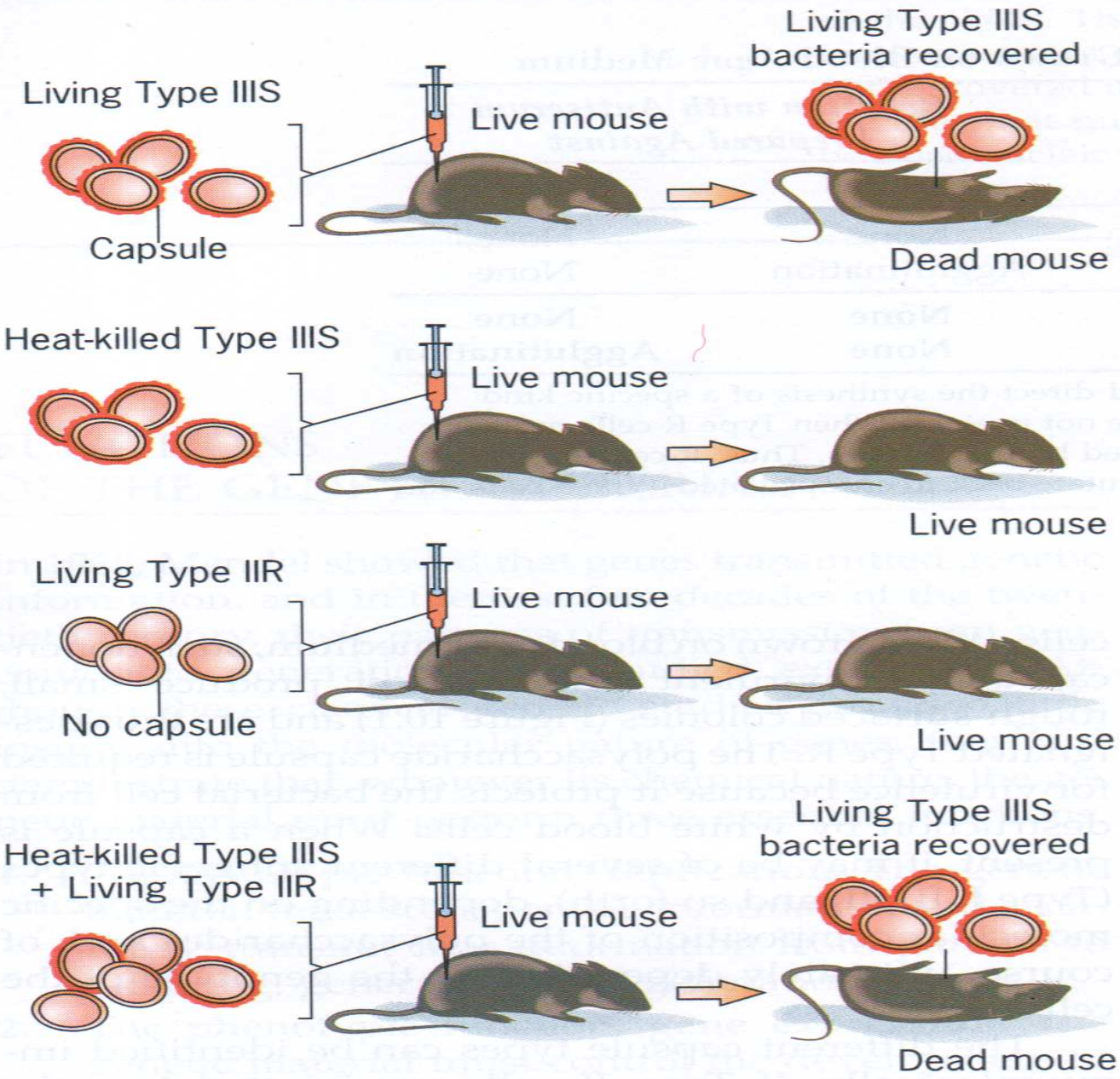


Figure 10.2 Griffith's discovery of transformation in *Streptococcus pneumoniae*.

Avery , Macleod & Maclyn Experiment :

- The next group of investigators , led by Oswald Avery worked *invitro* (in laboratory glassware) , this group published a paper that demonstrated that the transforming substance is DNA . the details as following :
- In 1943, Oswald Avery, Colin Macleod, and Maclyn McCarty, at the Rockefeller Institute, discovered that different strains of the bacterium *Strepotococcus pneumonae* could have different effects on a mice. One **virulent** strain could kill an injected mice, and another **avirulent** strain had no effect. When the virulent strain was heat-killed and injected into mice, there was no effect. But when a heat-killed virulent strain was coinjected with the avirulent strain, the mice died. What **transforming substance** was the dead virulent strain giving to the avirulent strain to make it lethal

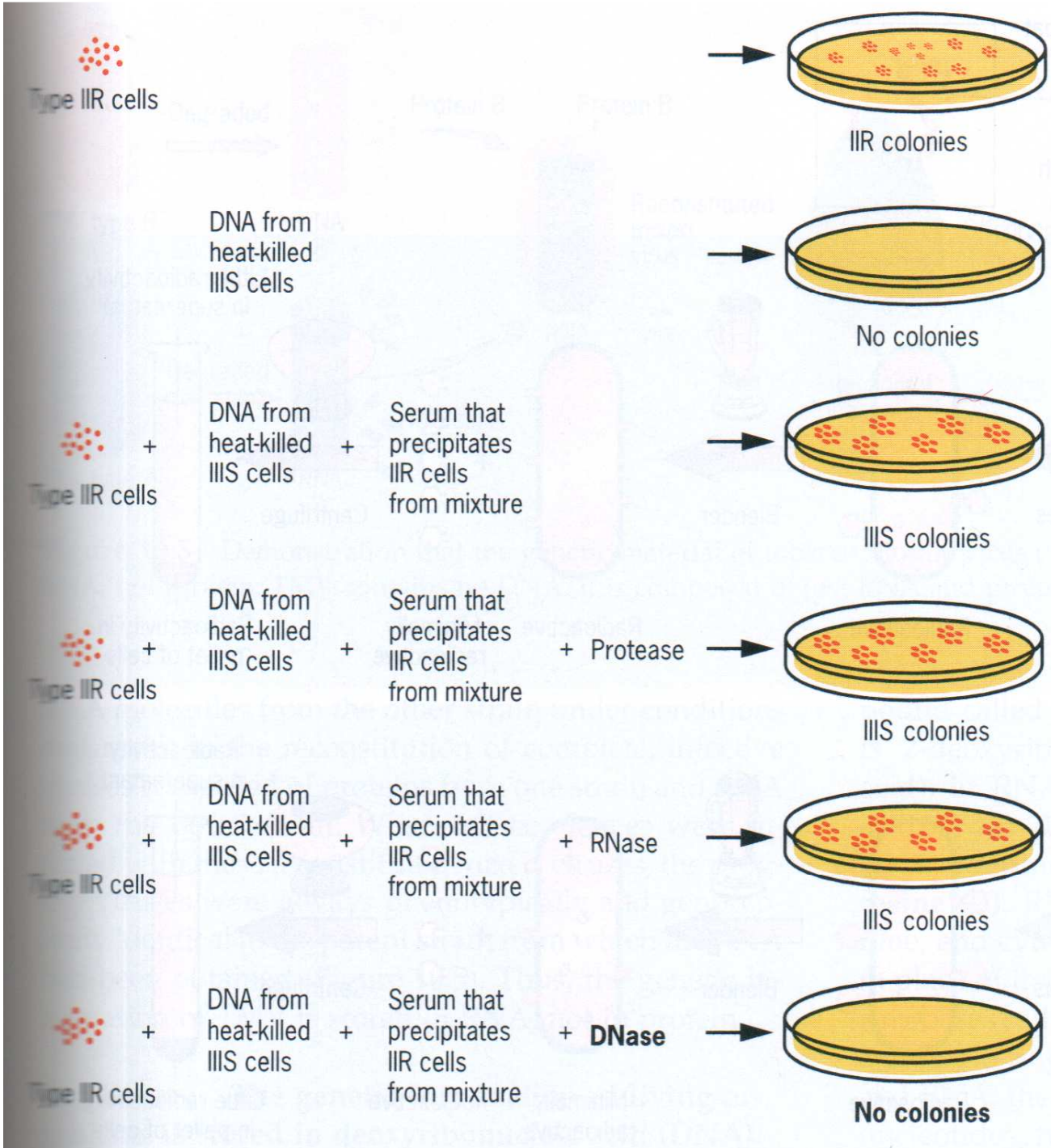
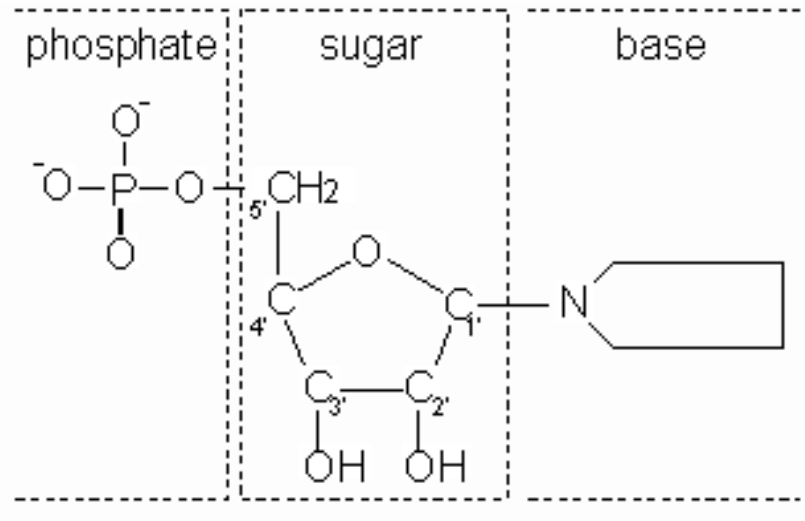


Figure 10.3 Avery, MacLeod, and McCarty's proof that the "transforming principle" is DNA.

Nucleic Acids

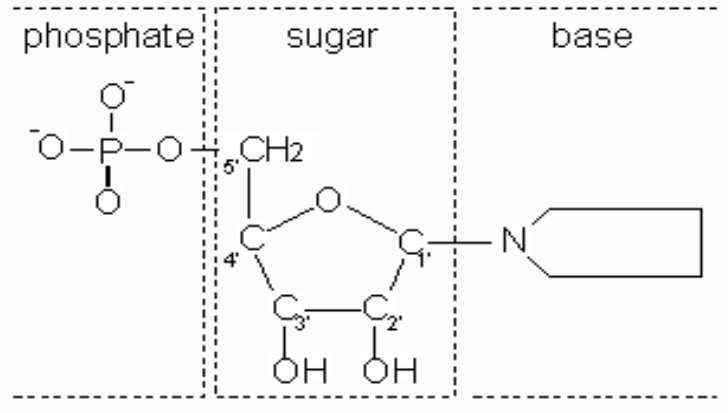
- DNA and its close relative RNA are perhaps the most important molecules in biology. They contains the instructions that make every single living organism on the planet, and yet it is only in the past 50 years that we have begun to understand them. DNA stands for deoxyribonucleic acid and RNA for ribonucleic acid, and they are called nucleic acids because they are weak acids, first found in the nuclei of cells. They are polymers, composed of monomers called **nucleotides**.

Nucleotides



- Nucleotides have three parts to them:
- 1-a phosphate group, which is negatively charged, and gives nucleic acids their acidic properties.
- 2-a pentose sugar, which has 5 carbon atoms in it. By convention the carbon atoms are numbered as shown to distinguish them from the carbon atoms in the base.

Nucleotide parts



- If carbon 2 has a hydroxyl group attached (as shown), then the sugar is ribose, found in RNA. If the carbon 2 just has a hydrogen atom attached instead, then the sugar is deoxyribose, found in DNA.

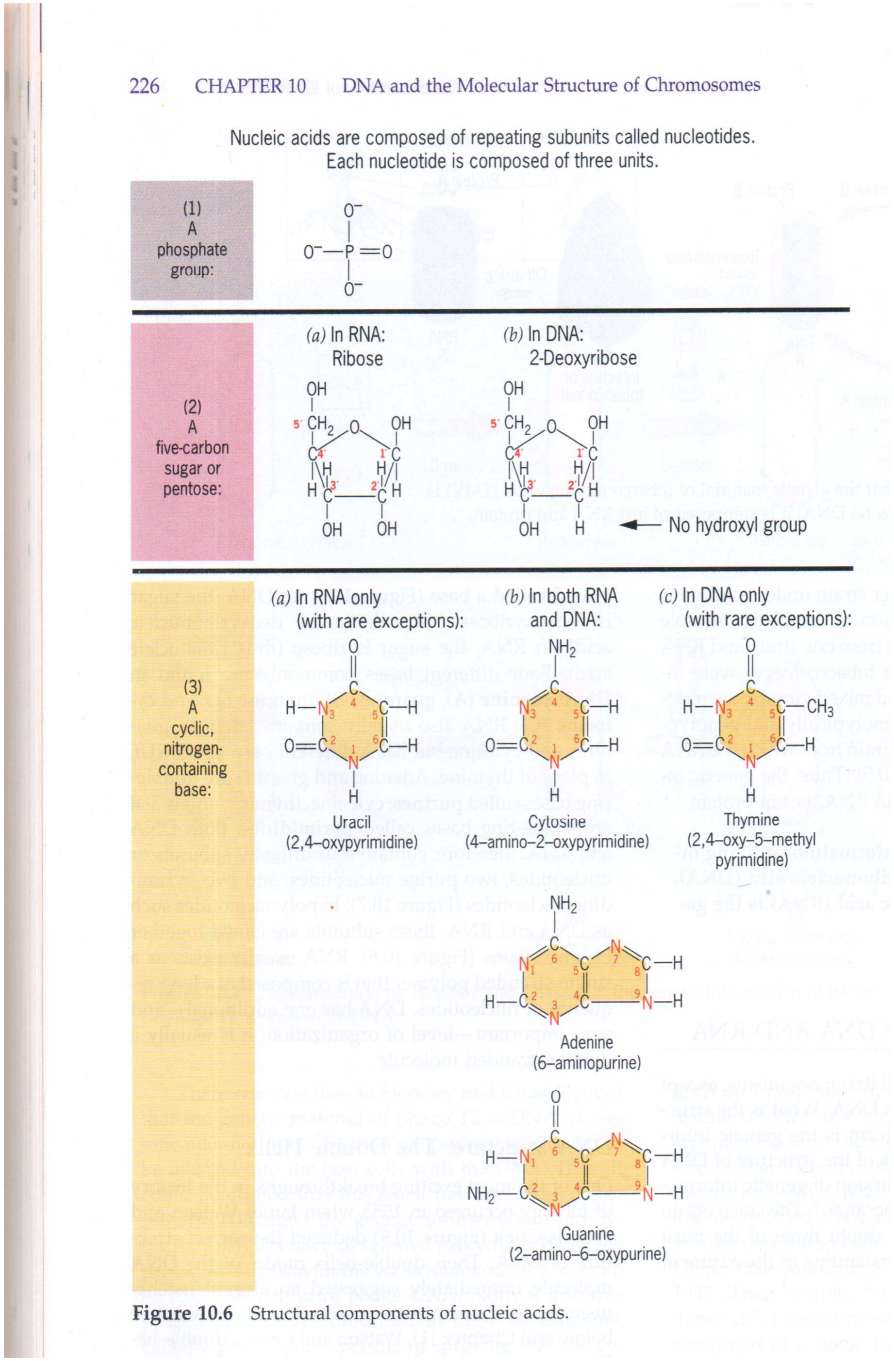


Figure 10.6 Structural components of nucleic acids.

- 3-a nitrogenous base. There are five different bases (and you don't need to know their structures), but they all contain the elements carbon, hydrogen, oxygen and nitrogen. The bases are usually known by there first letters only,

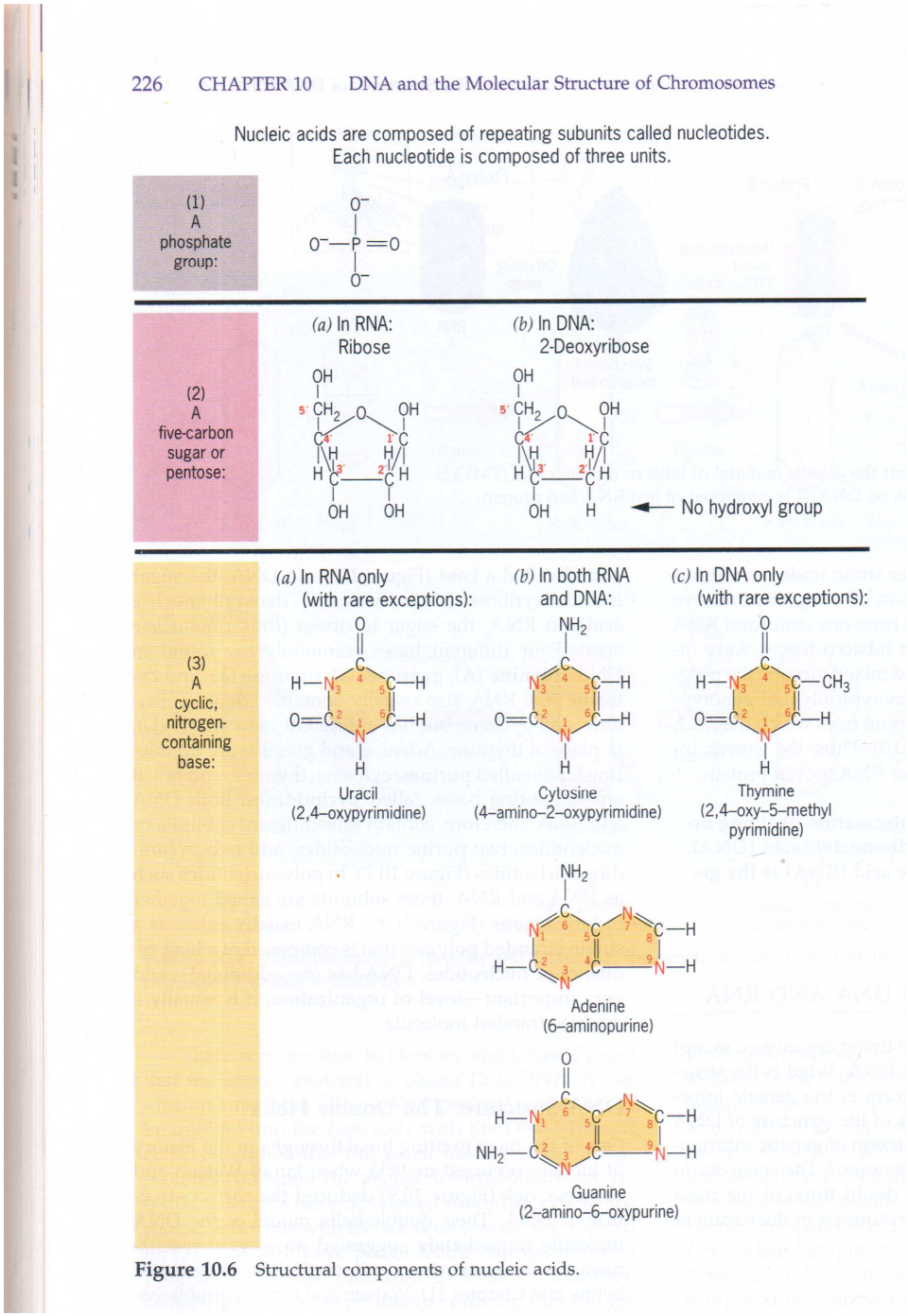


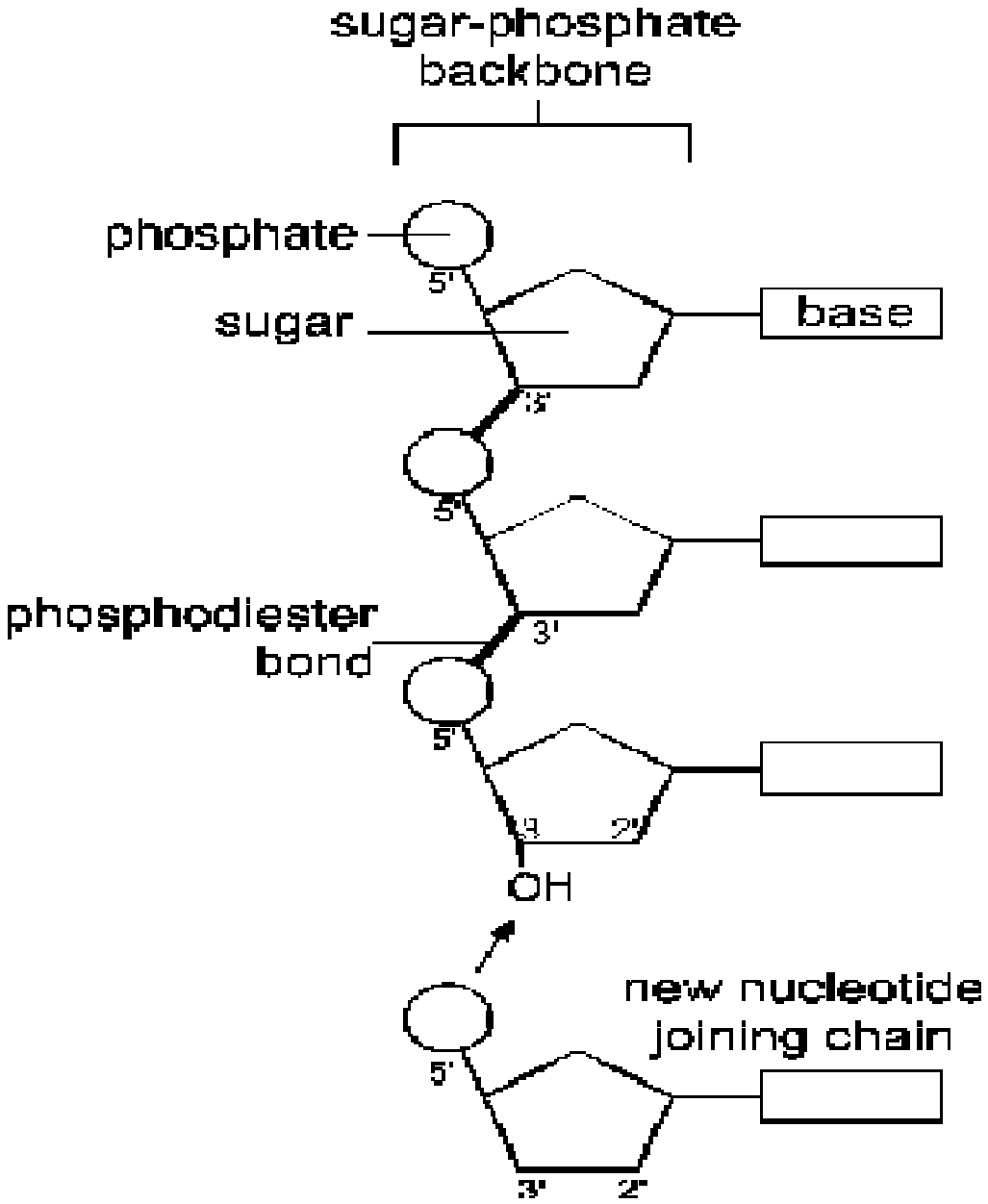
Figure 10.6 Structural components of nucleic acids.

- so you don't need to learn the full names. The base thymine is found in DNA only and the base uracil is found in RNA only, so there are only four different bases present at a time in one nucleic acid molecule. Nitrogen Bases are:

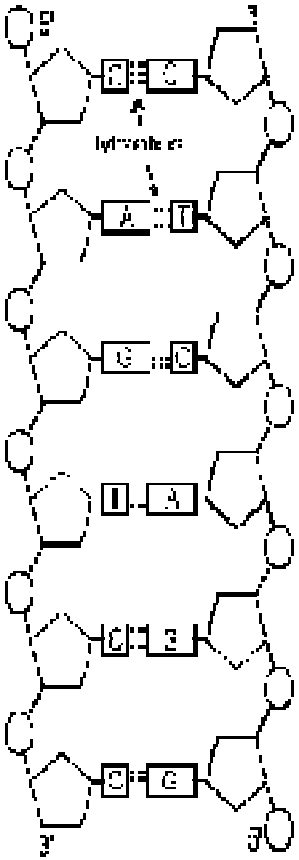
- Adenine (A)
Guanine (G)
Cytosine (C)
Uracil (U)
Thymine (T)

Nucleotide Polymerisation

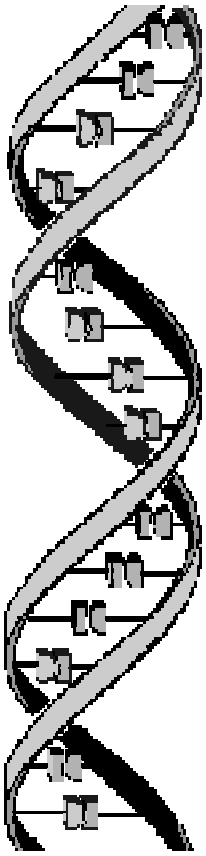
- Nucleotides polymerise by forming bonds between carbon 3 of the sugar and an oxygen atom of the phosphate. This is a condensation polymerisation reaction. The bases do not take part in the polymerisation, so there is a sugar-phosphate backbone with the bases extending off it. This means that the nucleotides can join together in any order along the chain. Many nucleotides form a polynucleotide.
- A polynucleotide has a free phosphate group at one end and a free OH group at the other end.


sugar-phosphate
backbone
phosphate
sugar
base
phosphodiester
bond
OH
new nucleotide
joining chain

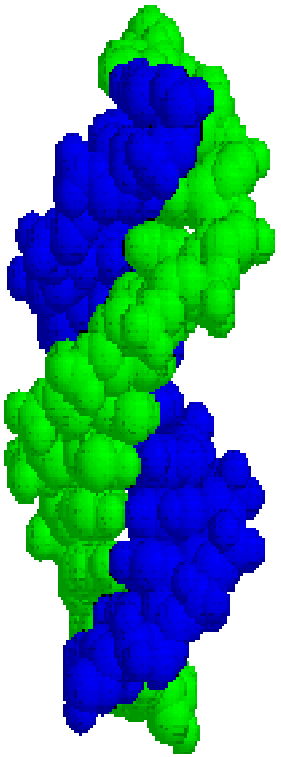
Structure of DNA



DNA showing the complementary base pairing between antiparallel strands

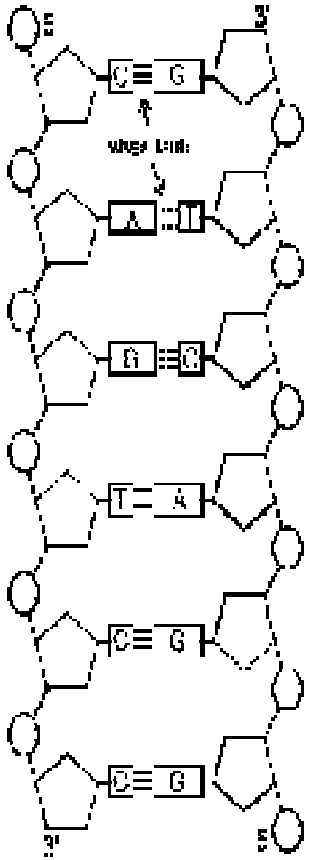


DNA showing the double helix

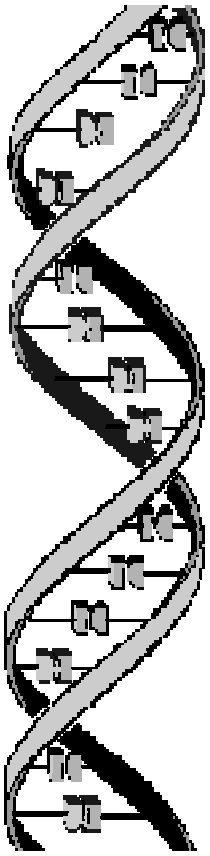


space-filling model of the double helix

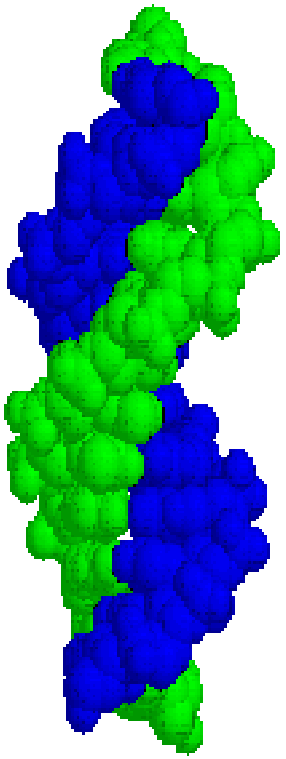
- The three-dimensional structure of DNA was discovered in the 1950's by Watson and Crick. The main features of the structure are:
- DNA is double-stranded, so there are two polynucleotide stands alongside each other.



DNA showing the complementary base pairing between antiparallel strands

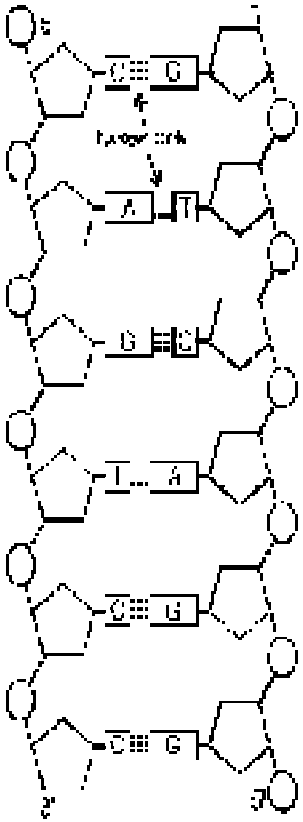


DNA showing the double helix

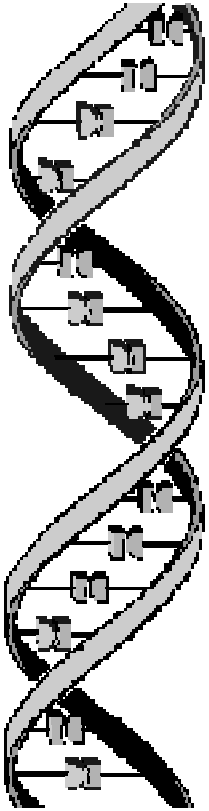


spacefilling model of the double helix

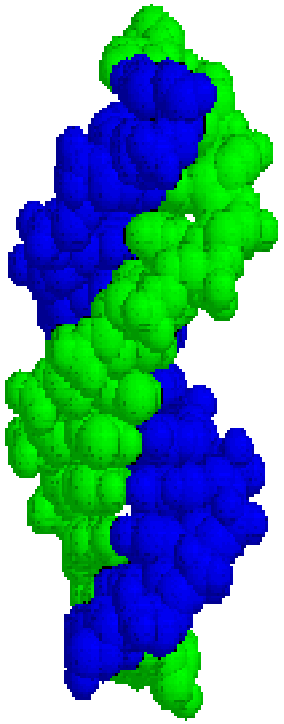
- The strands are antiparallel, i.e. they run in opposite directions.
- The two strands are wound round each other to form a double helix.
- The two strands are joined together by hydrogen bonds between the bases. The bases therefore form base pairs, which are like rungs of a ladder.



DNA showing the complementary base pairing between antiparallel strands



DNA showing the double helix

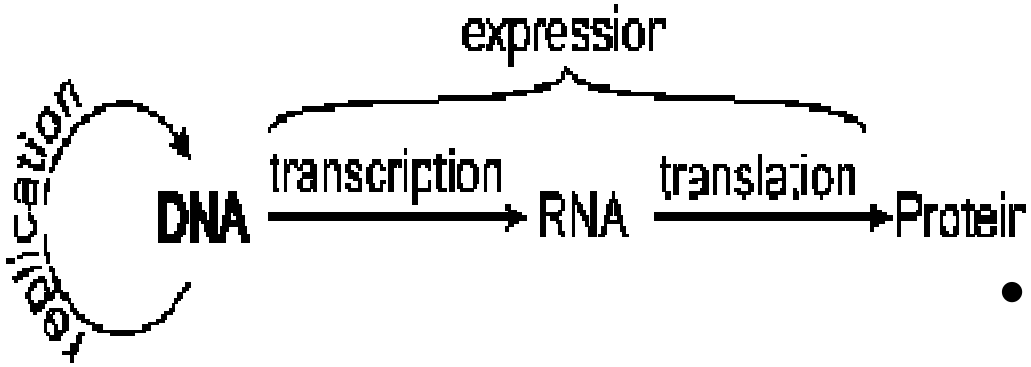


spacefilling model of the double helix

- The base pairs are specific. A only binds to T (and T with A), and C only binds to G (and G with C). These are called <u>complementary base pairs</u>. This means that whatever the sequence of bases along one strand, the sequence of bases on the other strand must be complementary to it. (Incidentally, complementary, which means matching, is different from complimentary, which means being nice.)

Function of DNA

- DNA is the genetic material, and genes are made of DNA. DNA therefore has two essential functions: replication and expression.
- Replication means that the DNA, with all its genes, must be copied every time a cell divides.
- Expression means that the genes on DNA must control characteristics. A gene was traditionally defined as a factor that controls a particular characteristic (such as flower color), but a much more precise definition is that a gene is a section of DNA that codes for a particular protein. Characteristics are controlled by genes through the proteins they code for.



- Expression can be split into two parts: transcription (making RNA) and translation (making proteins).
- These two functions are summarised in this diagram (called the central dogma of genetics).

- No one knows exactly how many genes we humans have to control all our characteristics,
- the latest estimates are 60-80,000. The sum total of all the genes in an organism is called the genome.

The table shows the estimated number of genes in different organisms:

Species	Common name	length of DNA (kbp)*	no of genes
phage l	virus	48	60
Eschericia coli	Bacterium	4 639	7 000
Drosophila melaogaster	fruit fly	165 000	~10 000
Homo sapiens	Human	3 150 000	~70 000

- Amazingly, genes only seem to comprise about 2% of the DNA in a cell. The majority of the DNA does not form genes and doesn’t seem to do anything.

RNA

RNA is a nucleic acid like DNA, but with 4 differences:

- 1-RNA has the sugar ribose instead of deoxyribose
- 2-RNA has the base uracil instead of thymine
- 3-RNA is usually single stranded
- 4-RNA is usually shorter than DNA

Messenger RNA (mRNA)

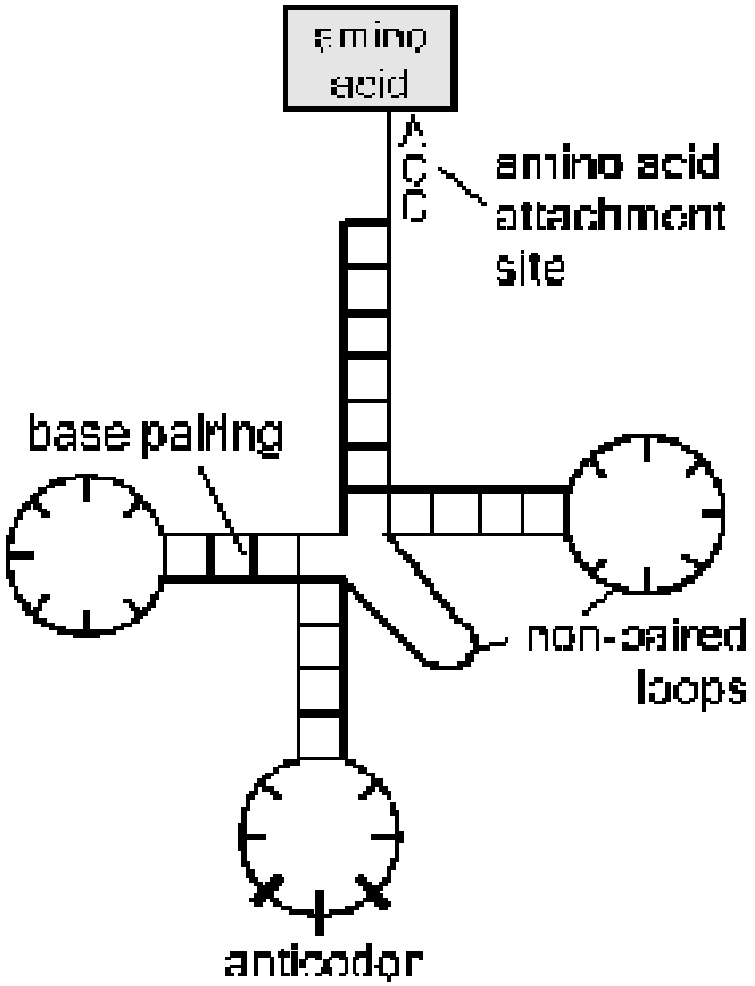
- mRNA carries the "message" that codes for a particular protein from the nucleus (where the DNA master copy is) to the cytoplasm (where proteins are synthesised). It is single stranded and just long enough to contain one gene only. It has a short lifetime and is degraded soon after it is used.

Ribosomal RNA (rRNA)

- rRNA, together with proteins, form ribosomes, which are the site of mRNA translation and protein synthesis. Ribosomes have two subunits, small and large, and are assembled in the nucleolus of the nucleus and exported into the cytoplasm.

Transfer RNA (tRNA)

- tRNA is an "adapter" that matches amino acids to their codon. tRNA is only about 80 nucleotides long, and it folds up by complementary base pairing to form a looped clover-leaf structure. At one end of the molecule there is always the base sequence ACC, where the amino acid binds. On the middle loop there is a triplet nucleotide sequence called the anticodon. There are 64 different tRNA molecules, each with a different anticodon sequence complementary to the 64 different codons. The amino acids are attached to their tRNA molecule by specific enzymes. These are highly specific, so that each amino acid is attached to a tRNA adapter with the appropriate anticodon.



Transfer RNA (tRNA)

The Genetic Code

- The sequence of bases on DNA codes for the sequence of amino acids in proteins. But there are 20 different amino acids and only 4 different bases, so the bases are read in groups of 3. This gives 4^3 or 64 combinations, more than enough to code for 20 amino acids. A group of three bases coding for an amino acid is called a codon, and the meaning of each of the 64 codons is called the genetic code.

The Genetic Code (mRNA codons)			
UUU, UUC: phe UUA, UUG: leu	CUU, CUC, CUA, CUG: leu	AUU, AUC, AUA: ile AUG: start/met	GUU, GUC, GUA, GUG: val
UCU, UCC, UCA, UCG: ser	CCU, CCC, CCA, CCG: pro	ACU, ACC, ACA, ACG: thr	GCU, GCC, GCA, GCG: ala
UAU, UAC: tyr UAA: stop UAG: stop	CAU, CAC: his CAA, CAG: gln	AAU, AAC: asn AAA, AAG: lys	GAU, GAC: asp GAA, GAG: glu
UGU, UGC: cys UGA: stop UGG: trp	CGU, CGC, CGA, CGG: arg	AGU, AGC: ser AGA, AGG: arg	GGU, GGC, GGA, GGG: gly

There are several interesting points from this code:

- 1-The code is degenerate, i.e. there is often more than one codon for an amino acid. The degeneracy is on the third base of the codon, which is therefore less important than the others.
- 2-One codon means "start" i.e. the start of the gene sequence. It is AUG.
- 3-Three codons mean "stop" i.e. the end of the gene sequence. They do not code for amino acids.
- 4-The code is only read in one direction along the mRNA molecule.

Replication - DNA Synthesis

- DNA is copied, or replicated, before every cell division, so that one identical copy can go to each daughter cell. The method of DNA replication is obvious from its structure: the double helix unzips and two new strands are built up by complementary base-pairing onto the two old strands.

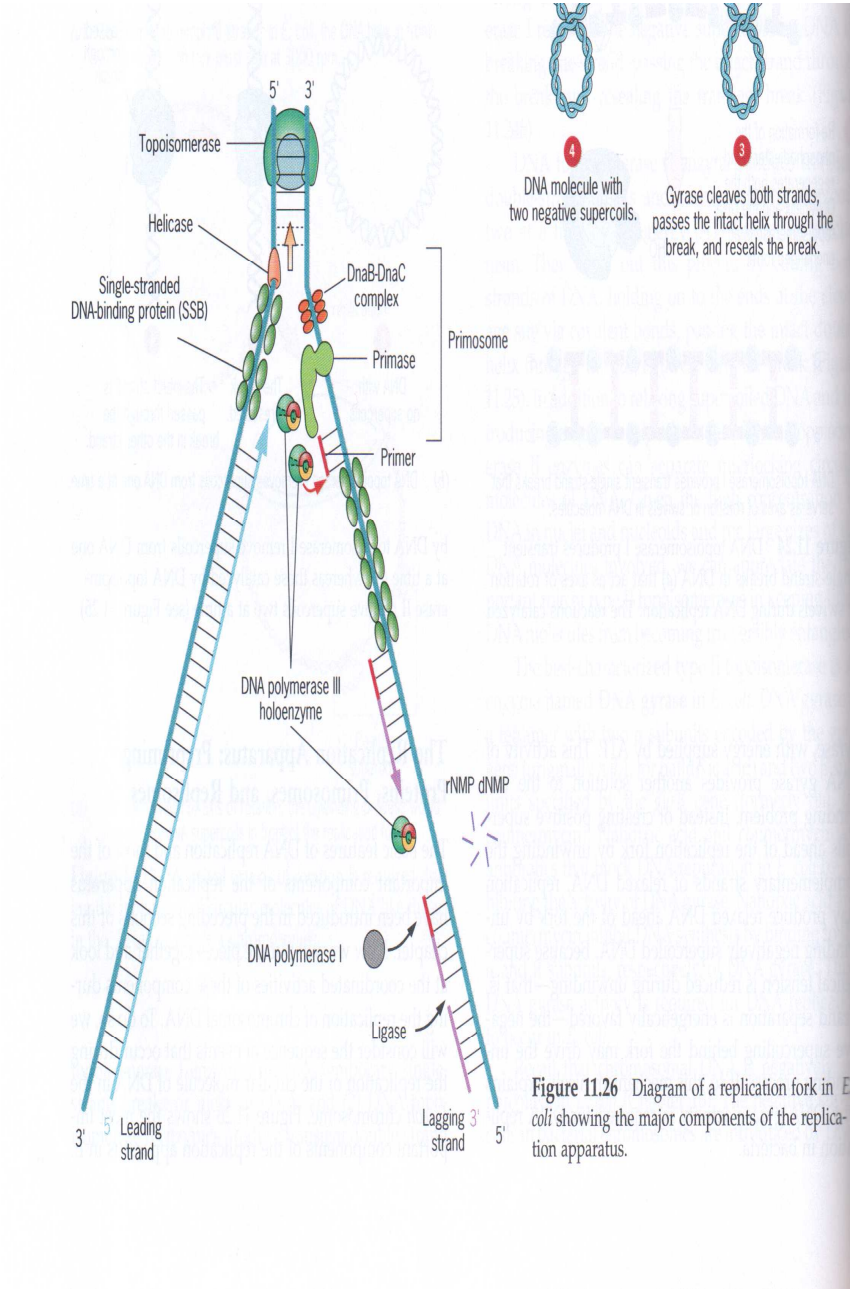


Figure 11.26 Diagram of a replication fork in *E. coli* showing the major components of the replication apparatus.

- Replication starts at a specific sequence on the DNA molecule called the <u>replication origin</u>.
- An enzyme unwinds and unzips DNA, breaking the hydrogen bonds that join the base pairs, and forming two separate strands.

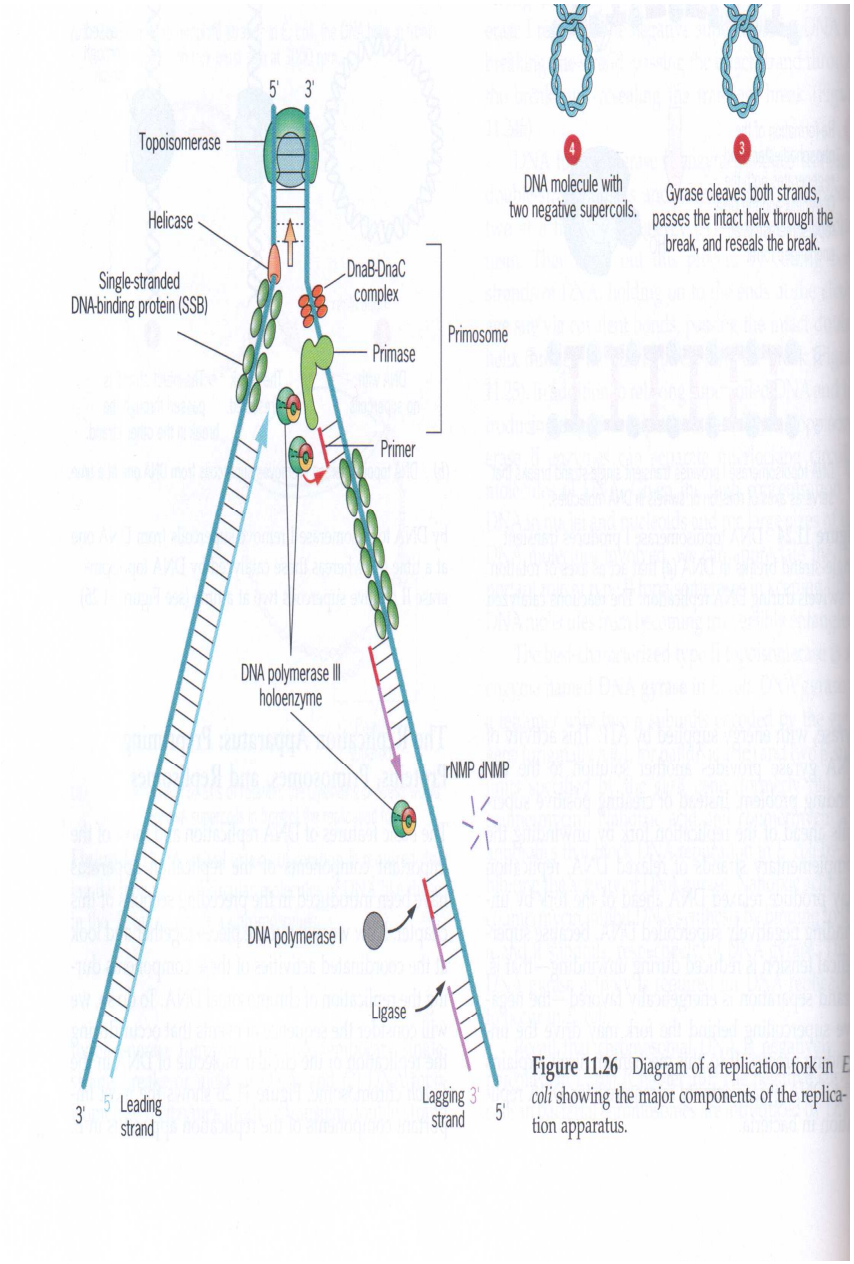


Figure 11.26 Diagram of a replication fork in *E. coli* showing the major components of the replication apparatus.

- The new DNA is built up from the four nucleotides (A, C, G and T) that are abundant in the nucleoplasm.
- These nucleotides attach themselves to the bases on the old strands by complementary base pairing. Where there is a T base, only an A nucleotide will bind, and so on.

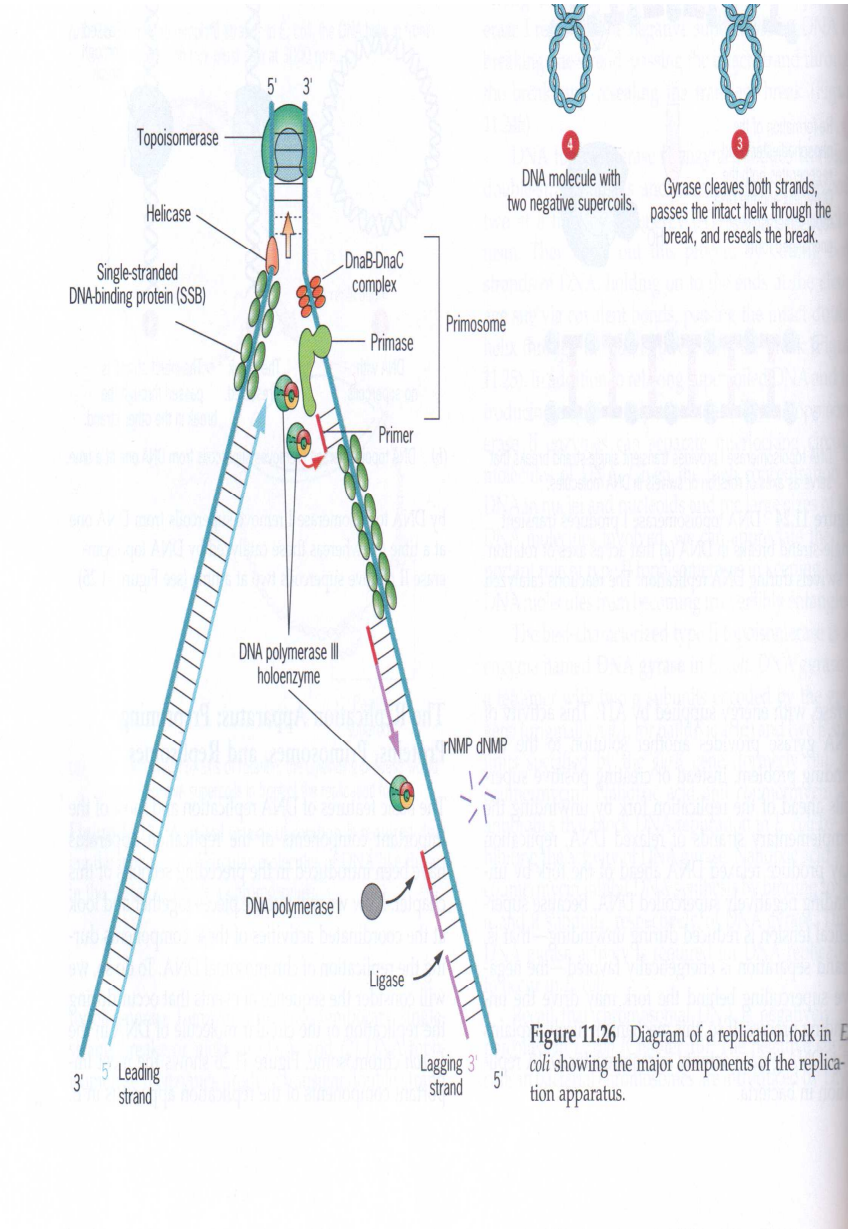


Figure 11.26 Diagram of a replication fork in *E. coli* showing the major components of the replication apparatus.

- A winding enzyme winds the new strands up to form double helices.
- The enzyme DNA polymerase joins the new nucleotides to each other by strong covalent bonds, forming the sugar-phosphate backbone.
- The two new molecules are identical to the old molecule

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- DNA replication can takes a few hours, and in fact this limits the speed of cell division. One reason bacteria can reproduce so fast is that they have a relatively small amount of DNA.

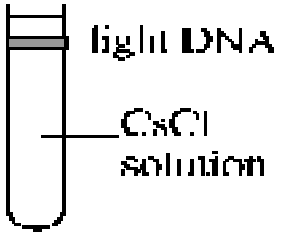
The Meselson-Stahl Experiment

- This replication mechanism is sometimes called semi-conservative replication, because each new DNA molecule contains one new strand and one old strand. This need not be the case, and alternative theories suggested that a "photocopy" of the original DNA could be made, leaving the original DNA conserved (conservative replication. The evidence for the semi-conservative method came from an elegant experiment performed in 1958 by Meselson and Stahl. They used the bacterium *E. coli* together with the technique of density gradient centrifugation, which separates molecules on the basis of their density.

The Meselson-Stahl Experiment

1. Grow bacteria on medium with normal $^{14}NH_4$

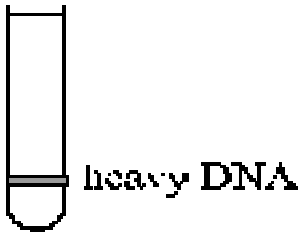
purify DNA and centrifuge



These first two steps are a calibration. They show that the method can distinguish between DNA containing ^{14}N and that containing ^{15}N.

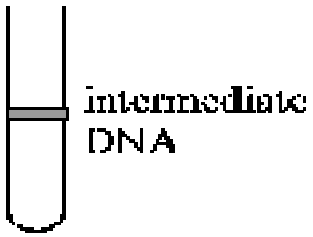
2. Grow bacteria for many generations on medium with ^{15}NH

purify DNA and centrifuge



3. Return to ^{14}NH medium for 20 mins (one generation)

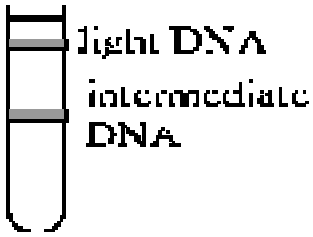
purify DNA and centrifuge



This is the crucial step. The DNA has replicated just once in ^{14}N medium. The resulting DNA is not heavy or light, but exactly halfway between the two. This rules out conservative replication

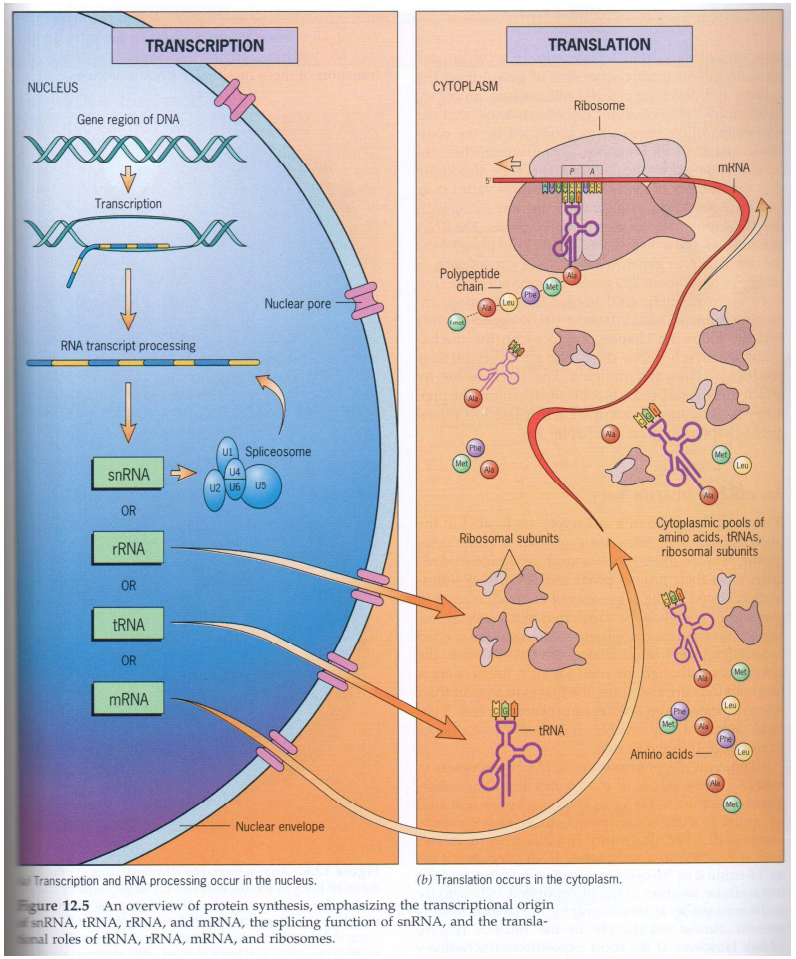
4. Grow on $^{14}NH_4$ medium for 40 mins (two generations)

purify DNA and centrifuge



After two generations the DNA is either light or half-and-half. This rules out dispersive replication. The results are all explained by semi-conservative replication.

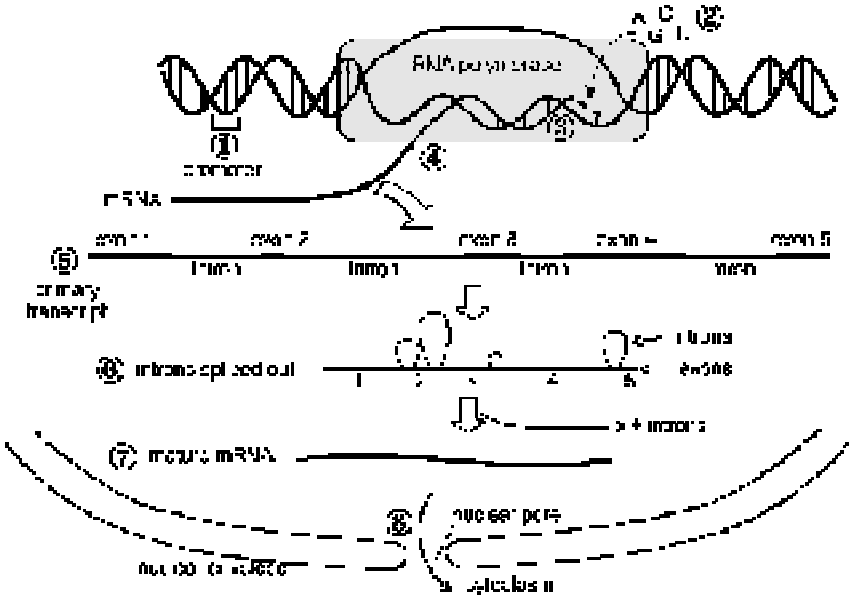
Transcription - RNA Synthesis



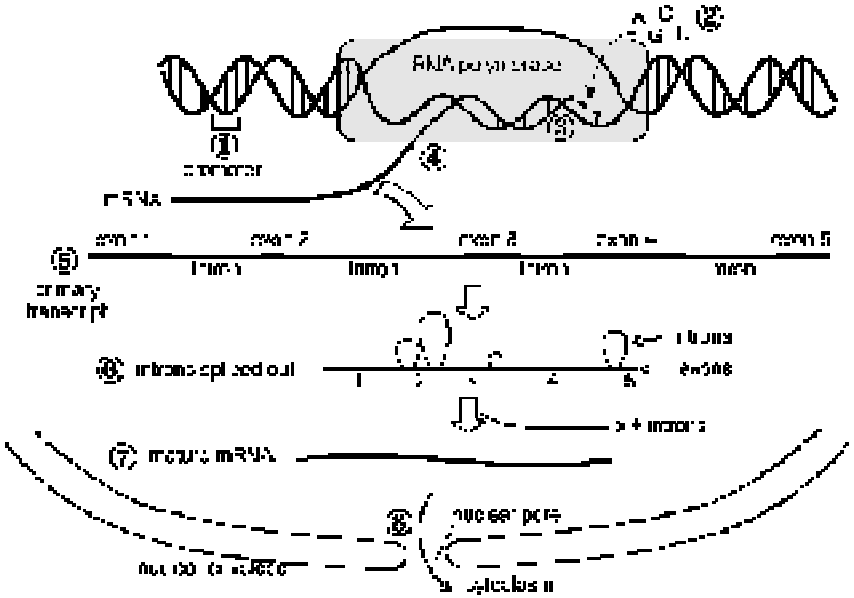
(a) Transcription and RNA processing occur in the nucleus. (b) Translation occurs in the cytoplasm.

Figure 12.5 An overview of protein synthesis, emphasizing the transcriptional origin of snRNA, tRNA, rRNA, and mRNA, the splicing function of snRNA, and the translational roles of tRNA, rRNA, mRNA, and ribosomes.

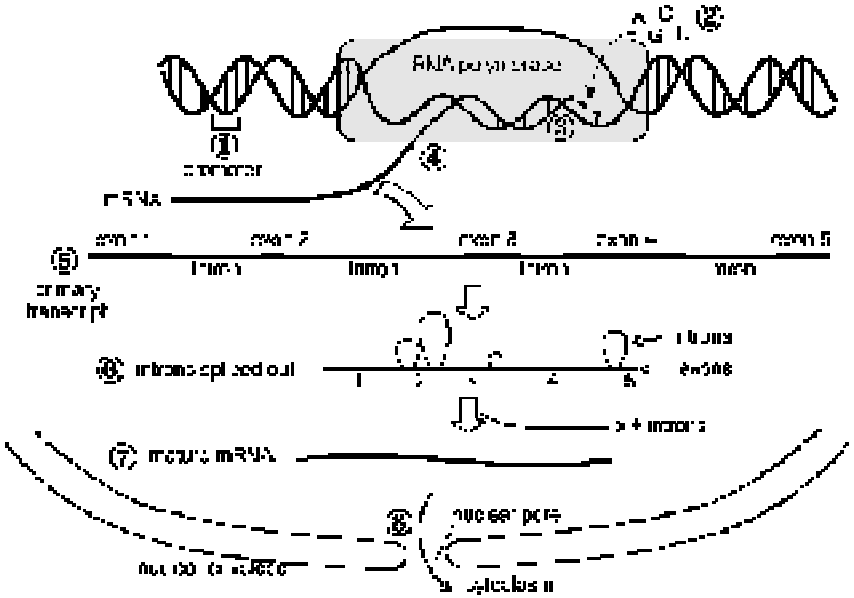
- DNA never leaves the nucleus, but proteins are synthesised in the cytoplasm, so a copy of each gene is made to carry the "message" from the nucleus to the cytoplasm. This copy is mRNA, and the process of copying is called transcription.



- The start of each gene on DNA is marked by a special sequence of bases.
- The RNA molecule is built up from the four ribose nucleotides (A, C, G and U) in the nucleoplasm. The nucleotides attach themselves to the bases on the DNA by complementary base pairing, just as in DNA replication.



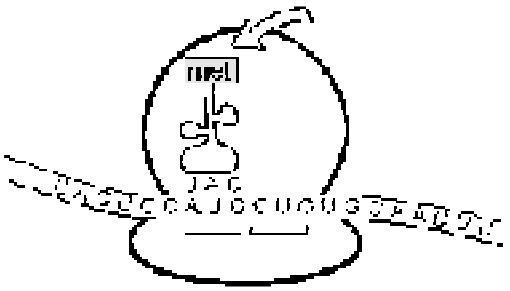
- However, only one strand of RNA is made. The DNA stand that is copied is called the template or sense strand because it contains the sequence of bases that codes for a protein. The other strand is just a complementary copy, and is called the non-template or antisense strand.
- The new nucleotides are joined to each other by strong covalent bonds by the enzyme RNA polymerase.

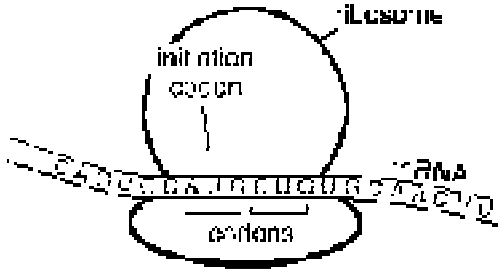


- Only about 8 base pairs remain attached at a time, since the mRNA molecule peels off from the DNA as it is made. A winding enzyme rewinds the DNA.
- The initial mRNA, or primary transcript, contains many regions that are not needed as part of the protein code. These are called introns (for interruption sequences), while the parts that are needed are called exons (for expressed sequences). All eukaryotic genes have introns, and they are usually longer than the exons.

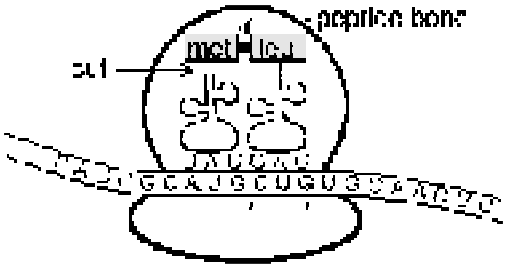
- The introns are cut out and the exons are spliced together by enzymes
- The result is a shorter mature RNA containing only exons. The introns are broken down.
- The mRNA diffuses out of the nucleus through a nuclear pore into the cytoplasm.

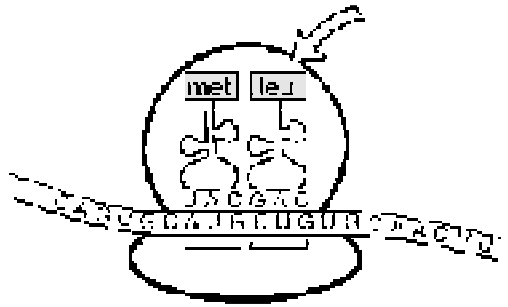
Translation - Protein Synthesis



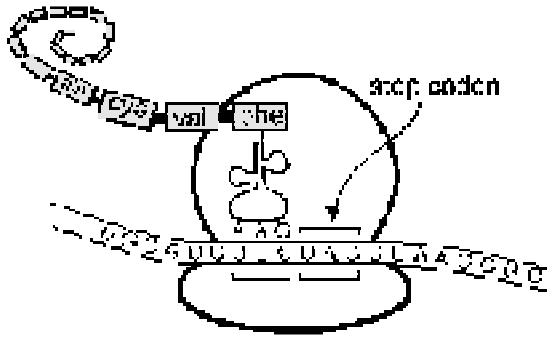


1. A ribosome attaches to the mRNA at an initiation codon (AUG). The ribosome encloses two codons.
2. met-tRNA diffuses to the ribosome and attaches to the mRNA initiation codon by complementary base pairing.

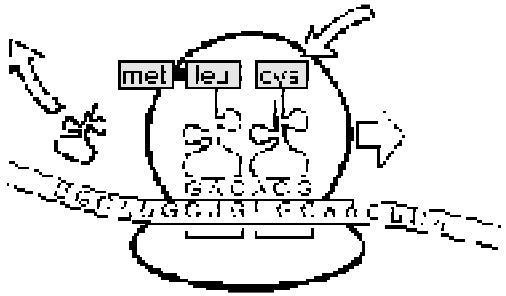




- 3. The next amino acid-tRNA attaches to the adjacent mRNA codon (leu in this case).
- 4. The bond between the amino acid and the tRNA is cut and a peptide bond is formed between the two amino acid



- 5. The ribosome moves along one codon so that a new amino acid-tRNA can attach. The free tRNA molecule leaves to collect another amino acid. The cycle repeats from step 3.



- 6. The polypeptide chain elongates one amino acid at a time, and peels away from the ribosome, folding up into a protein as it goes. This continues for hundreds of amino acids until a stop codon is reached, when the ribosome falls apart, releasing the finished protein.

- A single piece of mRNA can be translated by many ribosomes simultaneously, so many protein molecules can be made from one mRNA molecule. A group of ribosomes all attached to one piece of mRNA is called a polysome.

Post-Translational Modification

- In eukaryotes, proteins often need to be altered before they become fully functional. Modifications are carried out by other enzymes and include: chain cutting, adding methyl or phosphate groups to amino acids, or adding sugars (to make glycoproteins) or lipids (to make lipoporteins).